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Science Focus

A sneak peek at the
RI CHRISTMAS LECTURES

The futuristic farm of
PLANET EARTH III

11 gift ideas for
A BILLIONAIRE'S CHRISTMAS

A BLUEPRINT FOR ANTI-AGEING

The simple, science-backed changes that could slow, stop and maybe even reverse the sands of time

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FROM THE EDITOR

The mega-rich might not always age gracefully, but they do tend to age pretty well. Which is to say that they seem to have a knack for not only reaching old age in pretty good health, but carrying that good health deep into their advancing years.

Take Queen Elizabeth II, for example. She's thought to have had a personal fortune of almost £400 million and she managed to keep going until she was 96. Her Royal Highness was by no means an outlier, though. The average age of the top five in this year's *Sunday Times Rich List*, all active billionaire businessmen, is 75.6.

What's their secret? What's keeping them vital, active and energetic?

Wealth certainly helps: according to one study from 2020, being wealthy can add almost a decade of healthy life expectancy to your innings. Which, at first glance, could be fairly depressing news to those of us without the riches of Croesus. But, as scientists are discovering, it's not the whole story.

In fact, there are a number of small, simple (and in most cases, free) things you can do to improve your chances of uncoupling your biological age from your chronological age. And the good news is you may already be doing some of them. Turn to p58 to find out what they are and what effect they can have on your lifespan.

Speaking of the mega-rich, should you find yourself wondering what gifts they might be hoping to find under their trees this year, check out our guide to shopping like a billionaire this Christmas (p41). Don't worry, we've included a few real-world alternatives too, just in case you don't spend your days swimming in pits of gold coins like Scrooge McDuck. Happy holidays!

Daniel Bennett, Editor

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ON THE BBC THIS MONTH...

The Secret Genius of Modern Life
Whether its passports, vacuum cleaners or smartphones, the little things we take for granted often have fascinating and unexpected histories. Prof Hannah Fry delves into those objects' histories and meets some of the people who make them.
BBC Two, Wednesdays, 8pm
Also available on BBC iPlayer

Tooth and Claw: Cheetahs
Prof Adam Hart catches up with the fastest land animals in world. Cheetahs have an arsenal of physical adaptations that allow them to reach speeds of 110km/h (65mph) when pursuing their prey. But the predators themselves are under threat.
BBC World Service, 11 December 8.30pm GMT
Also available on BBC Sounds

The Reith Lectures 2023: Our Democratic Future
This year's lectures see Ben Ansell, Professor of Comparative Democratic Institutions at the University of Oxford's Nuffield College, looking at political systems. He'll examine some of the ways we can build political systems that work for all of us, while also being robust enough to meet the challenges of the 21st century, from artificial intelligence to climate change.
BBC World Service, 9 December, 7pm GMT
Also available on BBC Sounds

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VICTORIA GILL
The BBC's award-winning science correspondent takes a look at what's endangering the UK's countryside and what needs to be done to save it. → p32

DR HELEN PILCHER
The current limit for research on human embryos is 14 days. Scientists want to extend it further. Helen, a cell biologist, outlines the reasons why. → p34

PROF BILL MCGUIRE
Not all earthquakes happen at the boundaries between tectonic plates. Bill, a volcanologist, looks into the threat posed by intraplate quakes. → p72

CONTACT US

Advertising
David.DSouza@ourmedia.co.uk
0117 300 8110
Letters for publication
reply@sciencefocus.com
Editorial enquiries
editorialenquiries@sciencefocus.com
0117 300 8755
Subscriptions
ourmediashop.com/contactus
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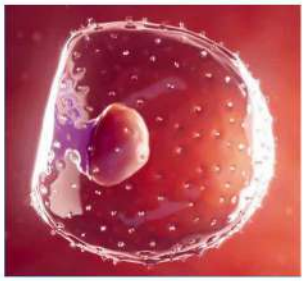

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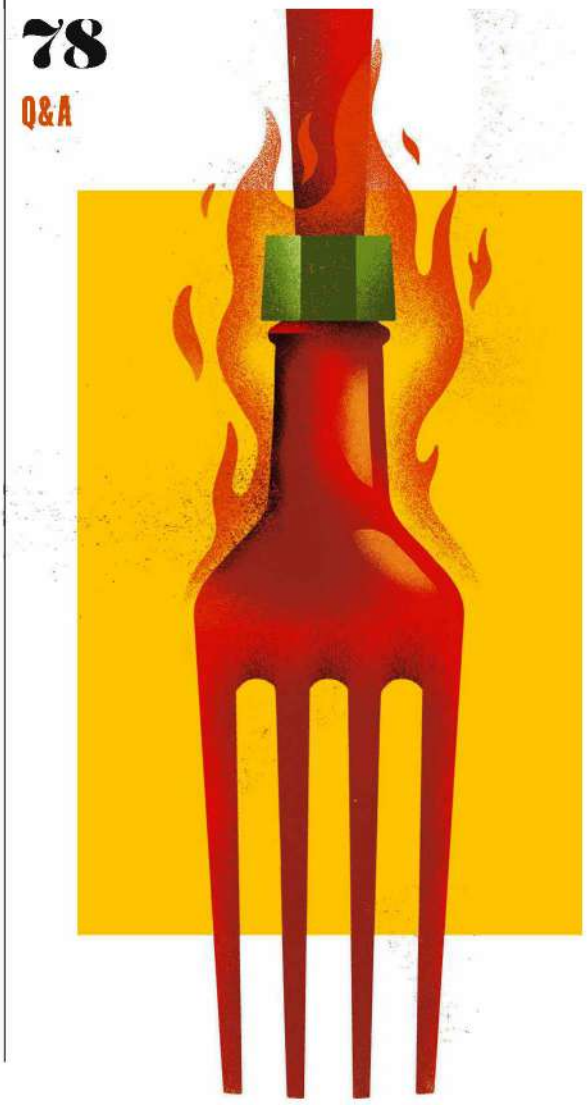

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EYE OPENER

Big boys' toys

TOKYO, **JAPAN**

What comes to mind when you think of Japan? The history, the culture, the food... or giant suits of transforming robotic armour? If you asked Ryo Yoshida, the 25-year-old chief executive of Tsubame Industries, the makers of this gigantic drivable robot, named Archax, he might be banking on you choosing the latter.

Designed to resemble the robots of the sci-fi anime series *Gundam*, Archax stands, on four wheels at a height of 4.5m (14.8ft) and weighs 3.5 tonnes (7,716lbs). Inside is a cockpit, which has enough screens, buttons and cameras to make a Bond villain jealous, as well as enabling a pilot to control Archax's legs, arms and hands to move objects and interact with its surroundings.

Archax can work in an upright robot mode or transform into a car that can travel at 10km/h (6mph). For now, only five will be made and each one is expected to cost 400 million yen (£2.1m). Initially, Archax will be marketed only to the uber-wealthy, but in the future, Tsubame Industries hopes it can be used in disaster relief and the space industry.

REUTERS

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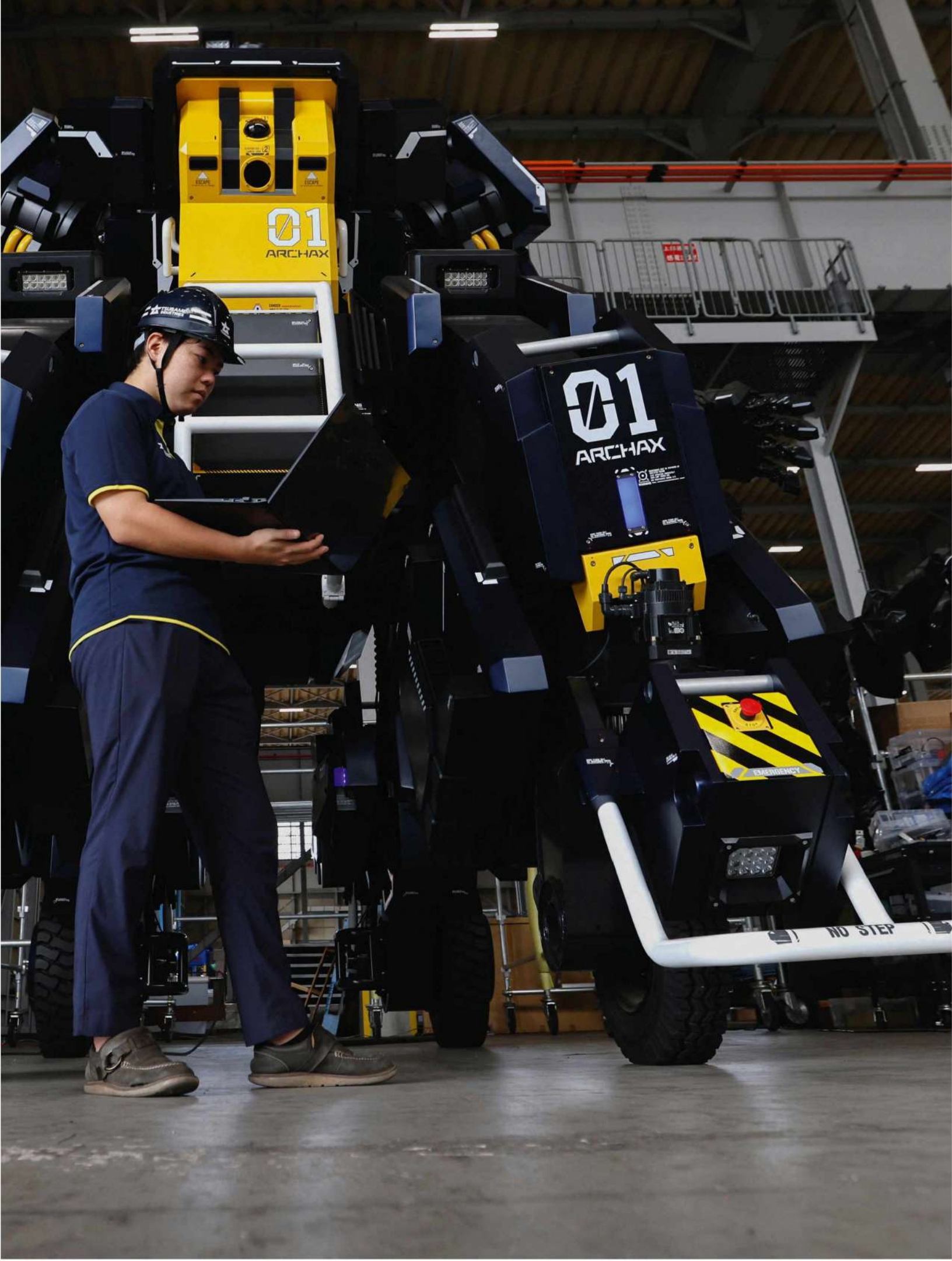
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ARCHAX
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ARCHAX
EMERGENCY
NO STEP

EYE OPENER

Flight paths

EMPORDA, SPAIN

Here, life is leaving the bare branches of a tree in a wintry Spanish landscape. But it isn't the last leaves of autumn being dramatically shed; instead, what you're seeing are starlings taking flight from its boughs.

This isn't a single photo, but a series of images that have been combined to track the otherwise invisible paths taken by hundreds, if not thousands, of starlings leaving their roosts and clustering in murmurations. "The resolution allows you to see individual wingbeats in a manner that wouldn't be possible from more static, traditional photographs," says ecophysiologist Dr Steve Portugal.

This innovative glimpse into the lives of starlings is the work of Spanish photographer Xavi Bou. He has been trying to capture this scene many times, sometimes going years without getting an image. "The sound is really impressive because the birds are very noisy when in the branches," Bou says. "But just before flying away they're in complete silence – after that, it's just the sound of their wings."

XAVI BOU

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EYE OPENER

Ancient dust

JOHNSON SPACE CENTRE,
HOUSTON

Having survived a seven-year-round trip to asteroid Bennu, the contents of this capsule from the NASA spacecraft OSIRIS-REx, which returned to Earth in September, could rewrite history as we know it.

It carries the largest-ever sample of rocks and dust from an asteroid. Scientists managed to collect 70.3g of material from the capsule's exterior (beating the mission's goal of 60g) before the sampler inside had even been opened.

Initial analysis has revealed the 4.6-billion-year-old sample is rich in carbon and water-containing minerals. Pristine and unaltered, it could hold secrets to the beginnings of life, providing a tangible snapshot into the formation of the Solar System.

As well as tracing the origins of the organic molecules that allowed life to evolve on Earth, the sample may help prevent future asteroid collisions. Bennu itself has a 1-in-2,700 chance of colliding with Earth in the year 2182.

Samples from Bennu will be sent around the world for study, with around 70 per cent of the material being kept for future generations.

NASA/JPL

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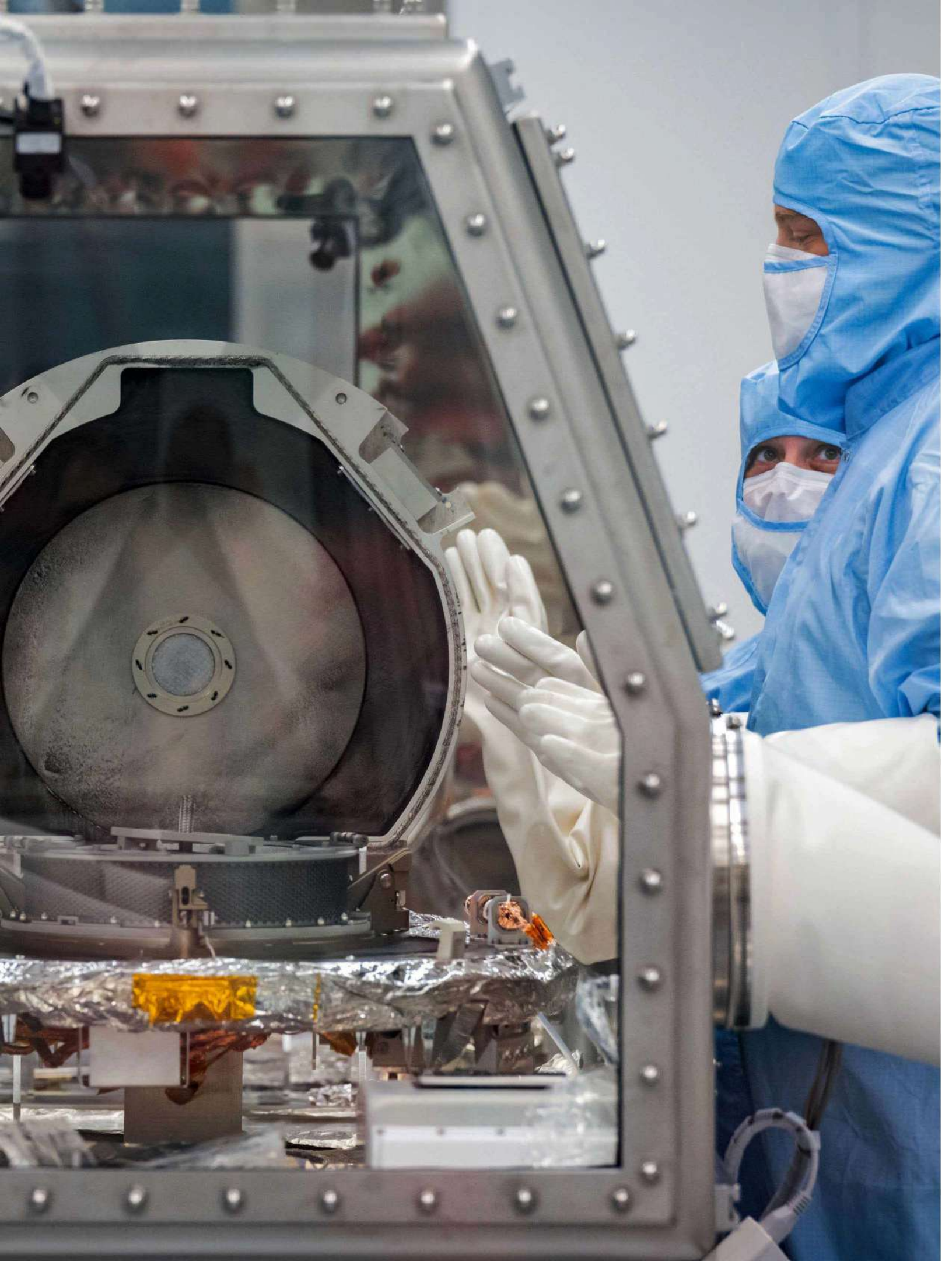

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YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND OUR MAGAZINE

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LETTER OF THE MONTH

Unforeseen benefits

While on holiday on Cornwall in September, looking around at the old tin mine engine houses got me in mind of your cover feature, 'Earth's Mysterious Core' (June, p66). With numerous articles on renewable energy, a thought occurred that an infinite supply of wind power was staring me right in the face: the mining chimneys. With the differential in air pressure creating a constant breeze upwards, would it just be a matter of adding a turbine inside each chimney stack, and off you go? Perhaps the people who built them were a couple of centuries ahead of their time.

Gary Stubbs, via email

WRITE IN AND WIN!

The writer of next issue's *Letter of the Month* wins an ***EZVIZ C3N Outdoor Smart Camera***. The C3N has three night-vision modes and AI-algorithm that detects human-shaped motion, ensuring no pets or local wildlife inadvertently set off the camera and its dual, built-in spotlights. Find out more at ezvizstore.co.uk.

An optimistic outlook

A Q&A answer (October, p81) addressed the question of what might happen if humans had to live permanently in space. It was suggested that, living in such a dangerous environment and being so dependent on technology could lead to an authoritarian and hierarchical society developing. To me, it seems to be just as likely that a democratic and egalitarian system would emerge, where people would cooperate for the common good and look out for each other, without a small group being in charge. In challenging situations, people rally round.

Paul Bennett, Manchester

Could the difficulty of living in space unify us?

Narrow escape

You mentioned the reason that the single house in the picture escaped the fire that devastated Maui (October, p8) is thought to be because the owners carried out renovations, which included surrounding the house with stones. I came across this practice some years ago while in France; it's essentially a soakaway. The stones aren't there for cosmetic reasons; they're the top layer of the soakaway required to drain away rainwater from the roof because the house doesn't have guttering or down pipes.

Tom Jones, via email

"ONE OF THE MOST POTENT STRATEGIES IN UNVEILING NEW TRUTHS IN PHYSICS ARISES FROM PRINCIPLES THAT UNIFY SEEMINGLY DISPARATE PHENOMENA"

PROF STEPHON ARMSTRONG, p30

Exercise may be part of the weight-loss puzzle, but it's only one piece of a complicated jigsaw

ALAMY X2, GETTY IMAGES

A question of scales

Prof Giles Yeo's take on exercise and weight loss was somewhat simplistic (October, p28). Have there been any peer-reviewed studies that show substantial weight loss can be achieved in two weeks, if caloric intake remains the same as pre-exercise levels and the intensities of exercise are not excessive? Losing weight from exercise is a complex dance between caloric intake, gain of lean body tissue, and caloric burn over timescales equal to years and decades – not hours and weeks. Anyone who expects to lose a percentage of their body fat or substantial excess weight in just two weeks doesn't understand what exercise can accomplish.

Sean Salamey, via email

Prof Giles Yeo replies: *While my take on exercise and weight loss narrowly focused on my own personal experience, it is supported by overwhelming population-based evidence. Would you lose weight if you exercised more, but controlled your diet? Undoubtedly, as can be seen in elite athletes for example. That, however, is not the reality for the bulk of the population.*

A matter of units

In the October issue, Alan Blackwood wrote in asking why we bother to use both metric and imperial units. Other readers have been writing in to let us know their thoughts...

I'm familiar with Celsius, but I was brought up with Fahrenheit and still relate to it more. Why is that perceived as a bad thing? Please continue to give both.

Delia Jarman, via email

Americans generally do *not* know the metric system. It isn't taught in schools. We know inches and feet, ounces and pounds, etc. But, somehow, we manage to get by.

Ira Penn, via email

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THE TEAM

EDITORIAL

Editor & brand lead Daniel Bennett
Managing editor Robert Banino
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Digital editor Thomas Ling
News editor Noa Leach
Staff writers Alex Hughes, Holly Spanner

ART

Art editor Joe Eden
Picture & asset manager James Cutmore

CONTRIBUTORS

Stephon Armstrong, Amy Arthur, Hayley Bennett, Peter Bentley, Steve Brusatte, Dean Burnett, Emma Davies, Sam Freeman, Denis Freitas, Victoria Gill, Alastair Gunn, Valentina Hernandez-Gomez, Oliver Hirst, Christian Jarrett, Pete Lawrence, Bernard Leonardo, Bill McGuire, Stephanie Organ, Ceri Perkins, Helen Pilcher, James Round, Eoin Ryan, Helen Scales, Andrew Steele, Ian Taylor, Sebastien Thibault, Luis Villazon, Jonny Wilkes, Giles Yeo and all the folks at VMG Digital.

ADVERTISING & MARKETING

Business development manager David D'Souza
Newstrade manager John Lawton
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kellie Lane

TECHNOLOGY

Senior Marketing Manager – Digital Editions Kevin Slaughter
Tech director Azir Razzak

INSERTS

Laurence Robertson 00353 876 902208

LICENSING & SYNDICATION

Director of International, Licensing & Top Gear Magazine, UK Tim Hudson
Head of Partners, Brand Management & Ethical Compliance Molly Hope-Seton
Head of Licensing Tom Shaw
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PRODUCTION

Production director Sarah Powell
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Publisher Andrew Davies
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BBC STUDIOS, UK PUBLISHING

Chair, editorial review boards Nicholas Brett
Managing director, consumer products and licensing Stephen Davies
Global director, magazines Mandy Thwaites
Compliance manager Cameron McEwan
UK.Publishing@bbc.com
www.bbcstudios.com

EDITORIAL COMPLAINTS

editorialcomplaints@immediate.co.uk

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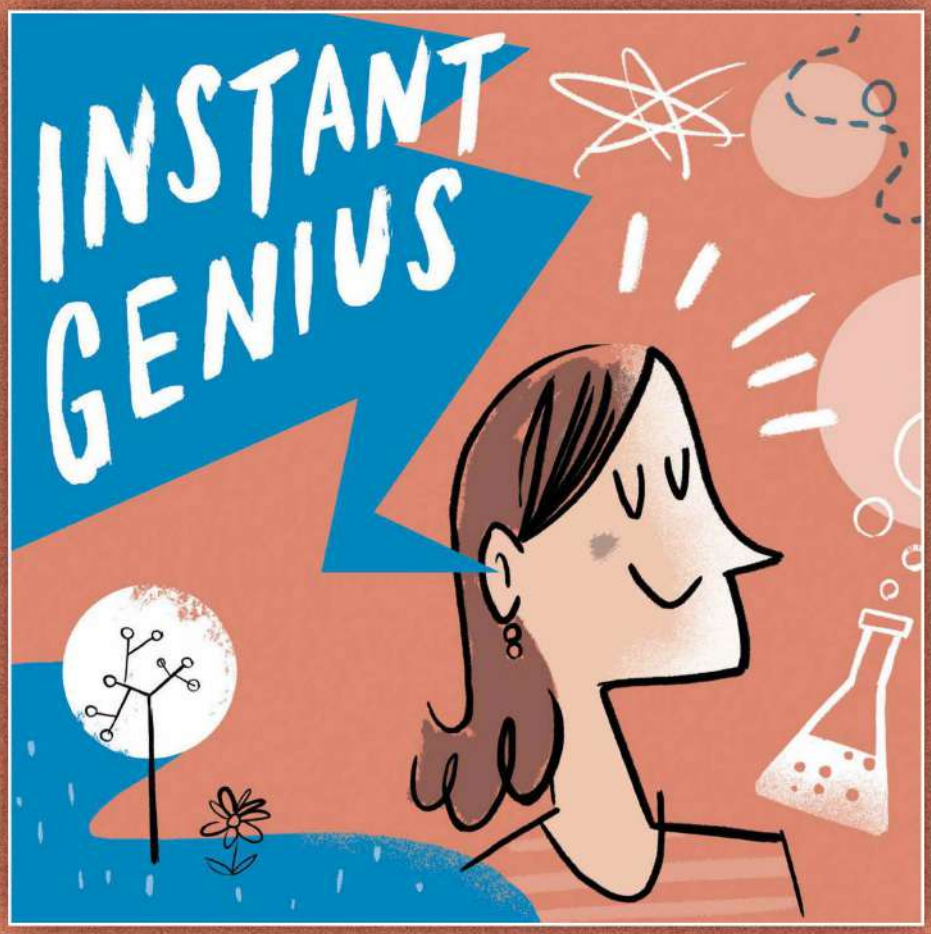

FEATURING

CAT PSYCHOLOGY
with
Dr Zazie Todd

PLASTIC POLLUTION
with
Dr Costas Velis

THE UNIVERSE
with
Dr Neil deGrasse Tyson

OCEAN CURRENTS
with
Dr Helen Czerski

DISCOVERIES

"As someone who has studied them for the last 10 years, these findings have radically changed the way I think about starfish"

Dr Jeff Thompson **p18**

TECHNOLOGY

ANYONE YOU RECOGNISE?

Police line-ups aren't working. Technology could improve them **p16**

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BURIED REMAINS

Shards of a planet that crashed into Earth are lodged deep within the mantle **p18**

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HEADS UP

Ever wondered where a starfish keeps its head? Now scientists know the answer **p18**

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CLOUDY WITH A CHANCE OF DEATH

Turns out it wasn't an asteroid that killed the dinosaurs. Well... not directly **p20**

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WHAT LIES BENEATH

A new unmanned drone intends to find out what's going on under the Antarctic's ice **p21**

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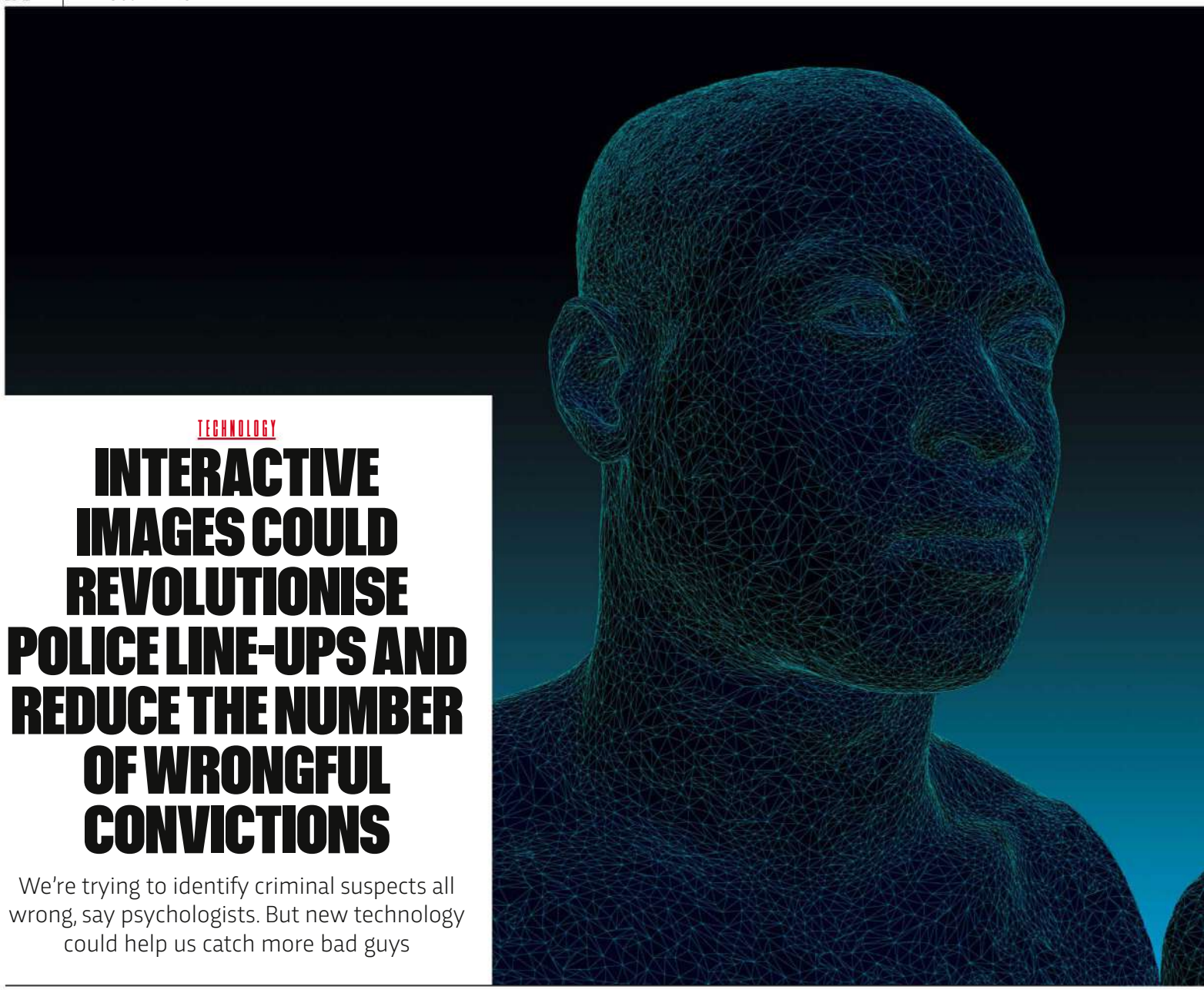
2023 IN SCIENCE

A look back at the biggest stories in space, physics, technology, health and medicine from the last 12 months **p22**

The first images captured by the European Space Agency's Euclid telescope reached Earth in November. Their arrival was just one of the many space stories that made headlines in 2023

ESA



TECHNOLOGY

INTERACTIVE IMAGES COULD REVOLUTIONISE POLICE LINE-UPS AND REDUCE THE NUMBER OF WRONGFUL CONVICTIONS

We're trying to identify criminal suspects all wrong, say psychologists. But new technology could help us catch more bad guys

A group of psychologists has argued that police line-up procedures don't help us identify suspects effectively. They say their new interactive technology could improve the chances of witnesses picking out the right person.

Rather than having witnesses choose from photographs of potential suspects, the new tech, developed by researchers at the University of Birmingham, allows witnesses to 'click and drag' images of potential suspects' faces. Doing so allows them to pull a suspect's face to the same angle as when the witness encountered them.

The researchers found that this sort of interactive viewing improves the accuracy of witness selection by 42 per cent. Even compared to video line-ups – when the suspects are filmed turning from side to side – the new technology improved selection accuracy by 20 per cent.

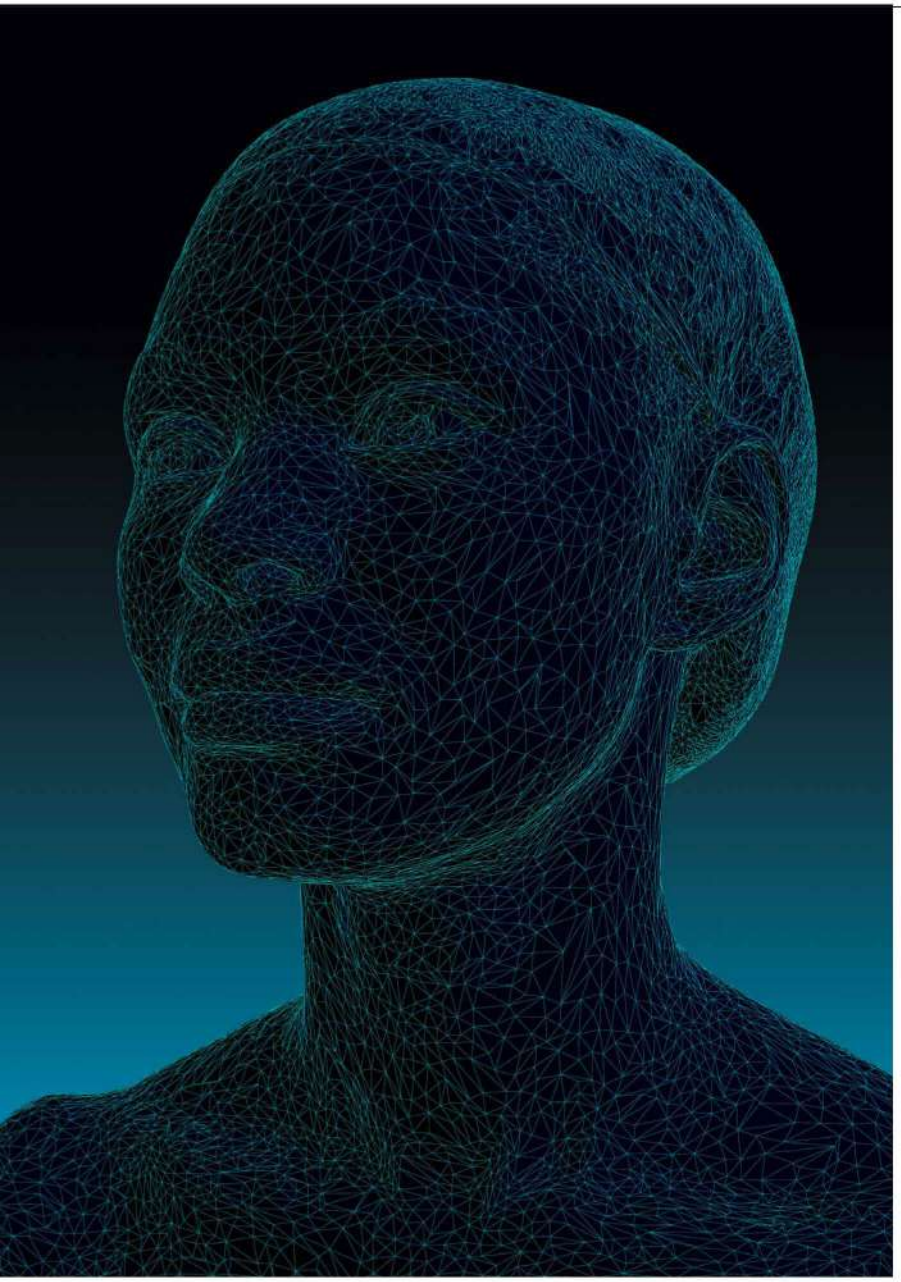
Psychologist Prof Heather Flowe has dedicated over nine years to this project. "We need to do better to

BETTER WAYS OF CATCHING CRIMINALS

"There are lots of cases where we just haven't thought about how witnesses saw the perpetrator," says Prof Heather Flowe.

The psychologist from the University of Birmingham recently wrote a paper about the Ted Bundy murders. One of the survivors saw Bundy from the side during his attack, then later had to pick his photo from a front-facing line-up. Bundy's defence challenged the victim on this, claiming that her choice must have been influenced by the familiarity of his image in newspapers. Flowe says, "we should show the witness what they actually saw."

GETTY IMAGES, PROFESSOR HEATHER FLOWE



JUSTICE WITH AI'S HELP

Prof Heather Flowe, a psychologist at the University of Birmingham, hopes that technology will help to bring static, front-on photos of suspects (such as the driver's licence pictures sometimes used in the US) to life.

Her next project is investigating the impact of showing witnesses different emotional expressions on suspects' faces. The team has already received a research grant to work on this with researchers from the Max Planck Institute in Germany, the University of Victoria in Canada and the University of Stirling in Scotland.

That's where artificial intelligence (AI) comes in. Flowe's group is testing the use of AI to create line-ups that generate photorealistic facial expressions – though she acknowledges that they need to explore caveats like AI falsely recreating someone's emotions.

In future, there's even the potential that AI could be used for contextual reinstatement: superimposing suspects into the crime scene with all the evidence in question.

"Existing line-up methods that police forces in the UK and US use are ineffective"

increase the odds that guilty people are identified while decreasing the odds that innocent people are selected from line-ups," she told *BBC Science Focus*.

Existing line-up methods that police forces in the UK and US currently use are ineffective and cause errors, according to Flowe. In America, suspects' photos don't even have to be consistent – they can range from the photo on someone's driver's licence to pictures of people in prison uniforms. "You have this hodge-podge line-up," Flowe said. "It's just not fair."

Current line-ups are missing tricks to help jog memories, she says, tricks that Flowe and her team are investigating. While her current technology allows witnesses to interact with the suspects' images, she and her team are testing ways to include dynamic facial movements, emotional expression, changes in lighting, and accessories such as masks. The thinking behind their work is that the more of these options you can provide a witness, the more accurate their choice will be. Her team is in discussion with police forces in the US and UK regarding testing the technology in the field.

"I'm excited to work with the police," Flowe said. "It's a good opportunity for police to get on board and start using better tech, [they're] still using photographs when we could do so much better."

SPACE

ALIEN PLANET DEBRIS DISCOVERED DEEP UNDER EARTH'S CRUST

A planetary collision so big that it formed the Moon also left behind remnants that changed Earth's mantle

Around 4.5 billion years ago, a massive collision with another planet changed Earth forever. Now, scientists have discovered that debris from the impact is still lodged inside our world. The pieces of material, measuring tens of kilometres, could be relics of an ancient protoplanet (a large body of matter in the process of developing into a planet) known as Theia, according to the scientists. Theia would have been Mars-sized when it crashed into proto-Earth.

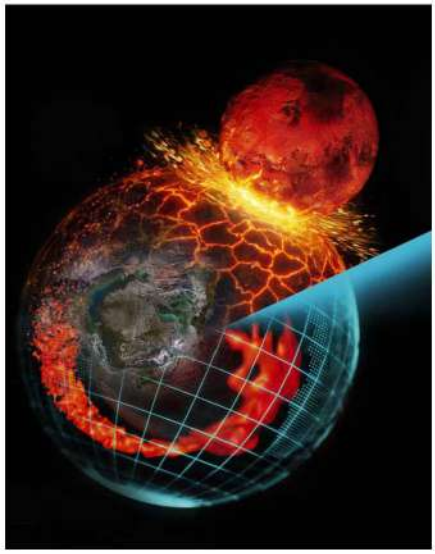
The new study, published in *Nature*, found that the debris of Theia buried and preserved under the crust forms up to two per cent of Earth's mass. The alien material is also denser than Earth's mantle and scientists think this is because it's enriched with iron, like Moon rock.

Many scientists already believe that the Moon was formed during the collision between Theia and Earth. Previous simulations suggest the Moon is mostly comprised of the alien protoplanet's shards. These same simulations also suggest that Earth was only lightly contaminated by Theia, given how little direct evidence of the protoplanet exists.

But the new study challenges this idea, instead showing that the impacts on Earth were significant.

For years, scientists have puzzled over anomalous seismic activity deep beneath Earth's crust. There are two places where seismic waves travel with mysteriously low velocities: beneath the African tectonic plate and under the Pacific tectonic plate. This affects tectonic plate structures, and therefore the joining and splitting of supercontinents.

To solve this puzzle, scientists from both the California Institute of Technology, USA, and Shanghai Astronomical Observatory (SHAO), China, ran computer simulations using calculations that involved high-resolution impact simulations, mantle convection models, mineral physics calculations and seismic imaging.



Dense shards of a protoplanet likely sank towards Earth's core after a massive collision

They discovered that the material in the two areas of low-velocity seismic waves is 2–3.5 per cent denser than the surrounding mantle. This high density likely caused the material, which could be shards of Theia, to sink towards Earth's core and form the low-velocity areas that have helped form the Earth as we know it.

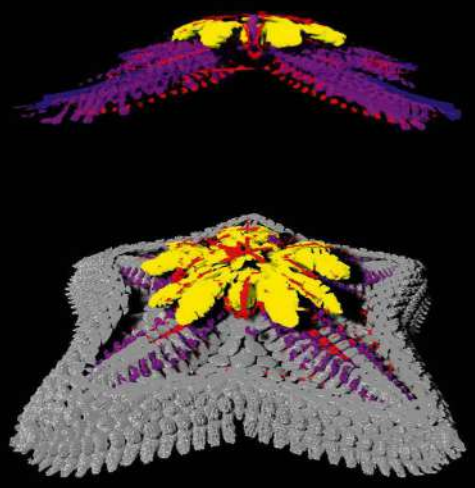
"The Moon-forming giant impact [likely] marks the starting point for Earth's geological evolution over the course of 4.5 billion years," said Hongping Deng, associate professor at SHAO and one of the paper's authors,

The findings could help us learn more about the formation of Earth, the Moon and exoplanets beyond our Solar System.

NATURE

SCIENTISTS FINALLY FIND WHERE A STARFISH KEEPS ITS HEAD

Compelling research into their genes sheds light on the echinoderm's enigmatic physiology

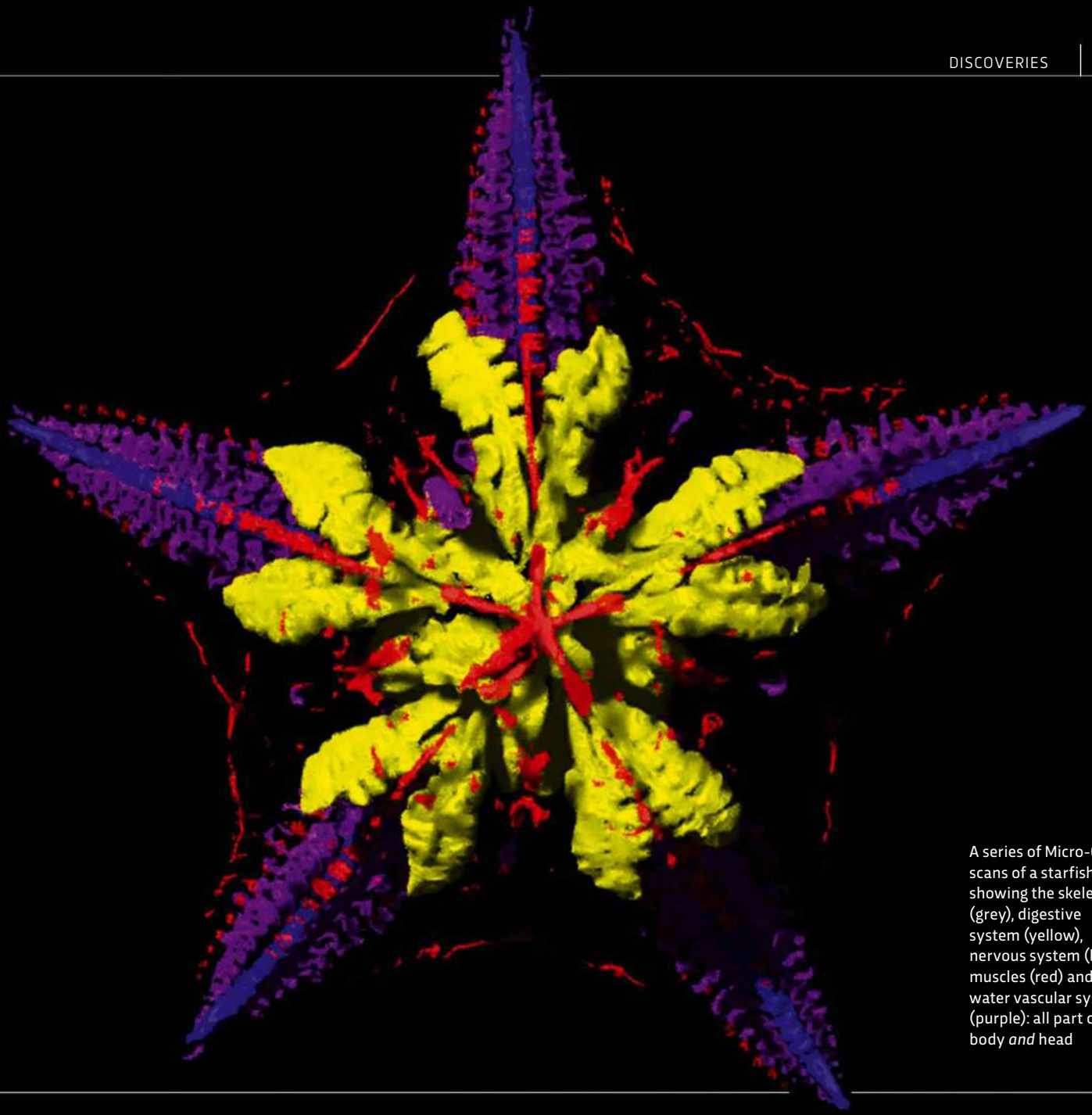


From their ability to regrow limbs to the conundrum of identifying where their bodies end and their heads begin, starfish are often at the centre of scientific intrigue. When it comes to that latter query, at least, scientists may finally have the answer.

Researchers from the University of Southampton are suggesting that, rather than their heads being part of their bodies, the entire bodies of starfish – and other echinoderms – *are* their heads.

Echinoderms, a group of animals that includes sea urchins and sand dollars, have a 'fivefold symmetric' body plan. That means their bodies can be divided into five matching sections.

HERNAN CANELLAS, UNIVERSITY OF SOUTHAMPTON.



A series of Micro-CT scans of a starfish, showing the skeleton (grey), digestive system (yellow), nervous system (blue), muscles (red) and water vascular system (purple): all part of the body *and* head

"The whole echinoderm body is equivalent to bilateral animals' heads"

Bilateral animals (which includes humans and most of the animal kingdom) have two sides, left and right, which mirror each other but are independent. These are part of a body plan that's divided into a central trunk, a head and tail.

For the study, scientists first compared the molecular markers of a starfish to those of similar marine creatures. Using a variety of high-tech molecular and genomic techniques, they were able to understand where different genes were expressed during the development of starfish, resulting in their final shape and structure.

"When we compared the expression of genes in a starfish to other groups of animals, like vertebrates, it appeared that a crucial part of the body plan was missing," said Dr Jeff Thompson, a co-author on the study from the University of Southampton.

The missing element? The genes involved in the patterning of the trunk. Instead, they found that the whole echinoderm body is equivalent to bilateral animals' heads. The scientists believe echinoderms may have evolved away from their bilateral ancestors, losing their trunk to allow them to move and feed differently.

"Our research tells us the echinoderm body plan evolved in a more complex way than previously thought and there's still much to learn about these intriguing creatures," said Thompson. "As someone who has studied them for the last 10 years, these findings have radically changed how I think about this group of animals."

PALAEONTOLOGY

STUDY REVEALS WHAT REALLY KILLED THE DINOSAURS

It wasn't the meteor's impact, but the colossal clouds of dust it kicked up into the atmosphere that drove the mass extinction 66 million years ago

GETTY IMAGES, PIM KASKES, WINDRACERS/BRITISH ANTARCTIC SURVEY

A giant asteroid measuring 10km (6 miles) in diameter hitting Earth some 66 million years ago wasn't the main cause of death for the dinosaurs, according to a new study. The impact, which formed the Chicxulub crater in the Yucatán Peninsula, Mexico, released more energy than a billion nuclear bombs, but it was the dust it sent into the atmosphere that spelled the end for three quarters of life on Earth.

Published in the journal *Nature*, the study by a team of scientists from the Royal Observatory of Belgium suggests that clouds of fine silicate dust produced by pulverised rock sparked a dramatic period of global cooling.

"Clouds of fine silicate dust sparked a dramatic period of global cooling"

"The explosion wasn't really what doomed the dinosaurs and all the other species that died," palaeontologist Prof Stephen Brusatte, who was not involved in the study, explained to *BBC Science Focus*. "The dust and soot that went up into the atmosphere put Earth into a deep chill and blocked out the Sun for at least a couple of years, and with plants unable to photosynthesise, ecosystems would have collapsed like houses of cards. It was probably the tiniest

The pinkish-brown strata in this cross-section of soil at the Tanis site in North Dakota reveals debris ejected from the Chicxulub impact event

dust particles that had one of the greatest killing effects on life."

The asteroid also released sulphuric gases into the atmosphere, triggered wildfires and volcanic eruptions, and launched a years-long 'impact winter'. Ultimately, this wiped out 75 per cent of life on the planet, including nearly all non-flying dinosaurs and large mammals.

It has been previously thought that these gases and soot drove the Earth's drastic cooling. But an examination of rock materials from Tanis – a fossil site in North Dakota, US, well known for providing direct evidence of the Chicxulub asteroid – revealed a much higher distribution of fine silicate debris, measuring less than 8 micrometres (0.000008m) across, than expected.

Using data from the site, the researchers estimate that the dust could have remained in the Earth's atmosphere for 15 years following the impact, contributing to a 15°C (59°F) drop in surface temperature. According to the new simulations, dust, alongside sulphur and soot, would have blocked plants from photosynthesising for two years, killing off vegetation and setting off a chain reaction of animal extinctions.

In total, dinosaurs roamed the Earth for approximately 165 million years (in comparison, *Homo sapiens* have existed for 300,000 years). Following the asteroid and mass extinction events, life continued in the form of small avian dinosaurs and mammals, many of which would eventually evolve into Earth's current life forms.

GEOLOGY

AUTONOMOUS DRONE COULD REVEAL ANTARCTICA'S SECRETS

Understanding ancient tectonics will improve ice melt predictions

Deep under the Antarctic ice, geological forces are at work. Today's water flows and volcanic activity affect how much ice melts and how quickly. But some scientists are more concerned about tectonic activity of the past, as this may affect how quickly the ice above melts as a result of climate change.

The challenge is studying a landscape hidden beneath the ice. Enter the Windracers ULTRA (Uncrewed Low-cost TRAnsport) drone (right): an autonomous aircraft designed for extreme environments. The British Antarctic Survey (BAS) plans to use the drone to discover how historic tectonic events can affect ice melt in the future, in the hope of making more accurate predictions.

The technology will change the future of scientific monitoring in Antarctica and around the world, said Dr Tom Jordan, an aero-geophysicist at BAS. "It opens so many doors," he told *BBC Science Focus*. The drone is capable of carrying an array of sensors over the Antarctic that will scan the landscape beneath the ice, while its pilot and science team can remain safely back at base camp.

Dr Jordan will be part of a team from BAS and Windracers heading to Antarctica in early 2024 to test the drone over the course of a month. "Antarctica is the least understood place on the planet," he said. In some places, no tectonic data exists at all – largely due to fuel restrictions. The ULTRA will allow scientists to build more comprehensive scans so that they can map what's hidden beneath the ice.

In the future, artificial intelligence-driven swarms of drones could be sent to Antarctica to complete coordinated, self-guided missions.

What will the ULTRA drone look for?

The ULTRA can carry large cargoes of up to 100kg (220lb) and travel distances of 1,000km (621 miles) while using 90 per cent less fuel than existing aircraft, allowing it to be sent to remote locations.

Fitted with a removable floor, the drone is able to accommodate a range of sensors. Three sensors, in particular, will help the scientists build a clearer picture of the tectonic world under the Antarctic ice:

- *Magnetic sensors* detect the composition and patterns of different rocks
- *Gravitational sensors* measure rock density
- *Radar sensors* calculate ice thickness by using pulsing radio echoes

The scientists will also use a spectral signal camera and high-resolution cameras to measure meltwater and monitor populations of wildlife.

2023 IN SCIENCE

Whether it's unexpected discoveries or answers to questions we didn't know were being asked, science news is always breaking. Here's a selection of some our favourite stories from the fields of health, space, medicine and technology that made headlines over the last 12 months

HEALTH IN 2023

How to have an optimal day, according to research published in 2023

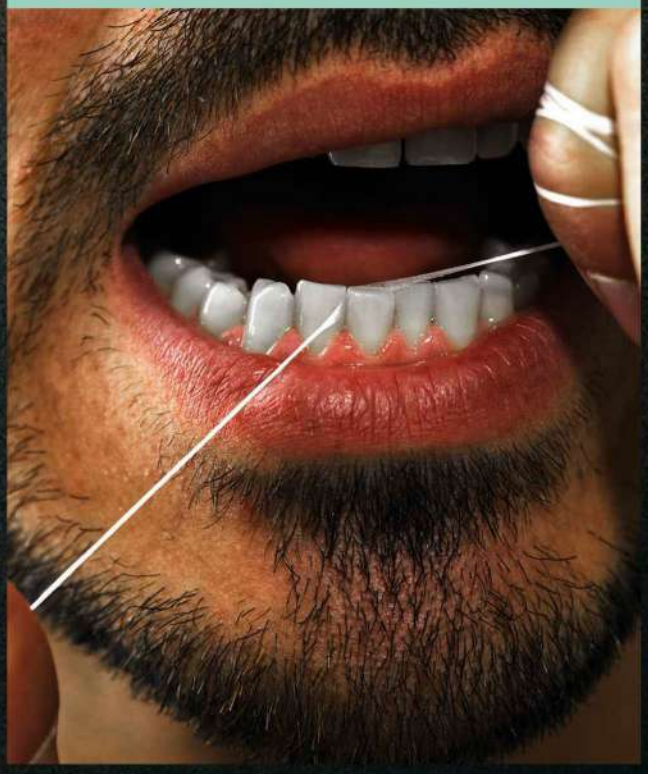
SET YOUR BEDROOM TEMPERATURE RIGHT

The importance of sleep was made clear by a number of studies this year. Getting a good amount of deep sleep is crucial to almost every aspect of our lives, so how can we get more of it? In August, a study by scientists at Harvard Medical School, in the US, found that sleep is most efficient and restful for older adults at temperatures between 15–25°C (60–77°F).

ENJOY A SNOOZE TO BOOST YOUR BRAIN

If you're enjoying a deep sleep when your alarm rings, there's no need to stop, according to a study published in October by researchers in Sweden. They found that people who hit the snooze button and had an extra 30 minutes in the land of nod were more likely to perform better in cognitive tests immediately after waking, than those who got up straight away. Turns out if you snooze, you *don't* lose.

GETTY IMAGES X3



BRUSH YOUR TEETH – AND BOOK YOUR NEXT TRIP TO THE DENTIST

If you're not doing this already, then a study published in September might change your mind. Published in the *Journal of the National Cancer Institute*, the study found that people who visit the dentist regularly and who have more of their natural teeth before receiving a diagnosis of either head or neck cancer, were more likely to survive the disease.

FORGET 10,000 STEPS... WALKING JUST 4,000 A DAY IS ENOUGH

If you fall short of your daily walking targets, cardiology research published in August might put a spring in your step. The research, published in the *European Journal of Preventive Cardiology*, revealed that health benefits start when you take as few as 3,867 daily steps – including reducing your risk of death from a range of causes.

KEEP GOOD NEWS TO YOURSELF

You might be able to make a good day even better – if you don't tell anyone about it. Contrary to popular belief, keeping secrets may not be a bad thing (as long as they're the right sort). In November, a study by scientists at Columbia University, in the US, found that keeping good news a secret actually boosts your energy levels – especially if you do eventually intend to spill the beans. Delaying by hours, days or even weeks could help prolong the joy involved in sharing your good news.

2023'S WEIRDEST WONDERS

THINK FAST

Friends fans: do you remember the episode where Phoebe helps the gang make decisions by asking quick-fire questions? Well, neuroscientists did the same this year with test participants to understand what makes the creative brain tick. Your better ideas, they suggest, may be the ones you think of faster.

CARTWHEELING SNAKES

Researchers identified a species of snake with an unusual gymnastic ability: it can do cartwheels. The dwarf reed snake was observed coiling itself into an S-shaped loop before using its tail to push off the ground and cartwheel 1.5m (4.9ft) in under five seconds. It's thought the behaviour is a bid to startle predators (and any scientists watching it).

OH, BER!

Parents and prudes were thrilled when mathematician Sophie Maclean wrote an algorithm that produced the 'ultimate swearword' without any lewd connotations. The acceptable expletive? 'Banger', or 'ber' for short.

PUCKER UP

Contrary to the teeth-baring portraits of the dinosaurs we've grown used to, a study published in *Science* showed that *Tyrannosaurus rex* probably had juicy (but scaly) lips. These smackers would have protected their giant gnashers from wear and tear.

SPACE IN 2023

April was packed with space news this year, thanks various celestial alignments that boosted the trajectory of launches. But the other 11 months of 2023 were also filled with fascinating discoveries, dramatic explosions and strange sightings...

5 JANUARY

JWST images the oldest-known barred galaxies

The James Webb Space Telescope catches sight of some of the oldest barred galaxies ever discovered. Two of the six spotted date back to when the Universe was 3.4 billion years old, a quarter of its current age.

3 APRIL

NASA introduces the next crew to go the Moon

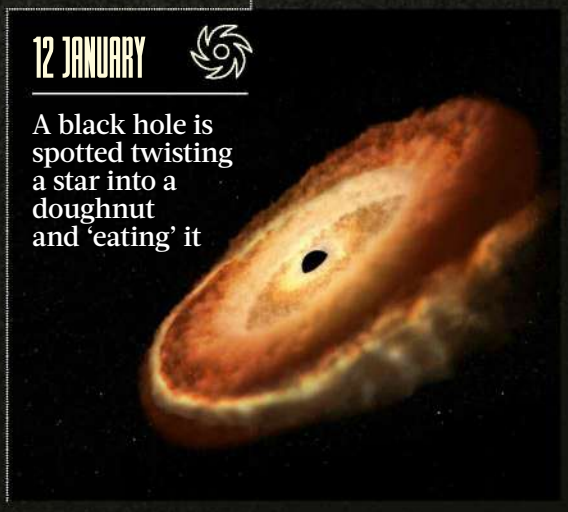
The crew of Artemis II, the first crewed mission to orbit the Moon in 52 years, is named. It includes Victor Glover (the first person of colour to go to the Moon), Reid Wiseman, Christina Koch (the first woman to go to the Moon) and Jeremy Hansen.

TIMELINE

Jan | Feb | Mar | Apr | May

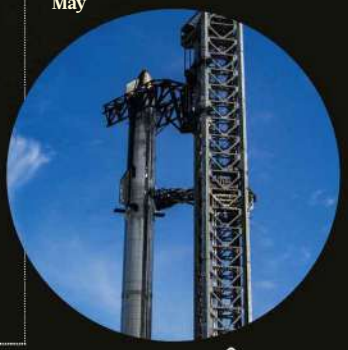
12 JANUARY

A black hole is spotted twisting a star into a doughnut and 'eating' it



14 APRIL

ESA launches the Jupiter Icy Moons Explorer mission



20 APRIL

SpaceX's Starship explodes in a fireball shortly after lift off

~2023~ in launches

Described as a "perfect launch", the Jupiter Icy Moons Explorer (JUICE) was sent to search the gas giant and three of its moons for evidence of life. Five months after JUICE's launch, the JWST detected carbon in the salty liquid ocean on Europa, confirming the moon as the most promising host for alien life.

2 JUNE

ESA celebrates the 20th birthday of its Mars Express camera with live footage of the Red Planet

1 JULY

Euclid launches to map the dark Universe and further our understanding of dark energy and dark matter

1 AUGUST

Euclid sends its first test images

23 AUGUST

India lands on the Moon

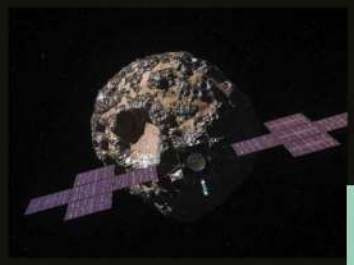
India becomes the first nation to achieve a soft landing at the lunar south pole – just days after Russia's failed attempt. But in September, the Indian Space Research Organisation announced it had lost communication with its Vikram lander.

24 SEPTEMBER

NASA's OSIRIS-REx returns a sample from the asteroid Bennu (see more on page 10)

13 OCTOBER

Psyche mission launches



Jun | Jul | Aug | Sep | Oct | Nov

19 JULY

A two-faced star is discovered

Scientists at Caltech reveal their discovery of a white dwarf made of hydrogen on one side and helium on the other. The hydrogen side appears brighter, while the darker, helium side bubbles and spits away behind it.

25 JULY

Scientists witness the start of giant planets being born

A new image from the European Southern Observatory shows clumps of dusty material orbiting a young star and assembling into spiral 'arms' bigger than our Solar System. If these collapse, they could form planets the size of Jupiter.

7 NOVEMBER

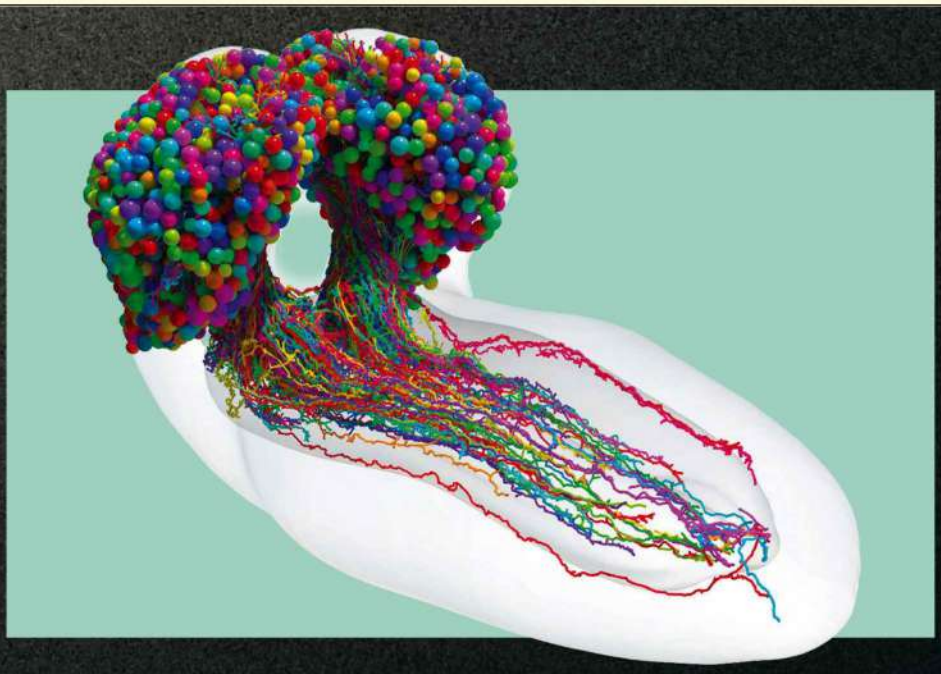
Euclid sends back its first colour images

After the initial launch on 17 April was halted during its final countdown, the SpaceX Starship lifted off on 20 April, only to explode minutes later when its first and second stages failed to separate.

The Psyche spacecraft launched successfully on 13 October. Scheduled to arrive at the asteroid that shares its name in 2029, the probe will study the metal-rich rock.

ALAMY, GETTY IMAGES X3, ESA X4, NASA/JPL X4, ESO/ALMA, JENNY HAUTMANN/SUPERCLUSTER/WIKIPEDIA, NASA/HUBBLE

MEDICINE IN 2023



MAPPING MINDS

2023 was a big year for neural cartography. In March, researchers at the University of Cambridge pieced together a map showing the links between every single neuron in the brain of a fruit fly larva – producing the stunning image shown here. Meanwhile, scientists at the Allen Institute for Brain Science, in the US, were beginning to map the 3,000-plus cell types that make up the human brain, with the first blueprint published in October.

BREAKING INTO THE BRAIN

A breakthrough method that uses ultrasound and bubbles to 'trojan horse' drugs across the blood-brain-barrier spells good news for potential Alzheimer's treatments. "It opens up this door of basically unlimited options," Dr Sophie Morse, the study's lead author told *BBC Science Focus* in September.

GREEDY GENE

Scientists from the University of Cambridge discovered that fetuses use a gene (IGF2) inherited from their fathers to force their mothers to release more nutrients during pregnancy. It was the first evidence that a dad's gene, nicknamed the 'greedy gene', allows his unborn child to send these demanding signals.

FLUSHED WITH HOPE

The first faecal transplant clinical trials began in the UK as the first trials in the US came to a close. In November, the US trials found that the transplants rid patients of drug-resistant superbugs. The UK trials are using a tablet (nicknamed a 'crapsule') to deliver the transplants to volunteers with liver disease.

TURNING BACK THE CLOCK

A breakthrough study by scientists at the Duke University School of Medicine, in the US, identified the human body's natural mechanism for reversing biological ageing. The research showed that biological age is more flexible than chronological age, and can be reduced – as long as we give our bodies a chance to recover from stressful events. Later in the year, a group of studies published in *Nature* suggested that transfusions of a young person's blood, and injections of an age-defying hormone, could help to rejuvenate ageing brains.

M WINDING ET EL/SCIENCE, GETTY IMAGES X3, UNIVERSITY OF TEXAS AT AUSTIN, SCIENCE PHOTO LIBRARY

THE BREAKTHROUGHS THAT MADE US FEEL GOOD ABOUT THE WORLD

MAY
Scientists unveiled a secret weapon in the fight against ecosystem loss this year – one that was created thousands of years ago by Indigenous people. Called 'dark earth', the incredibly fertile soil created by deposits such as charcoal from cooking fires left by Amerindian people in Brazil, could help us grow more climate-resilient forests fast.

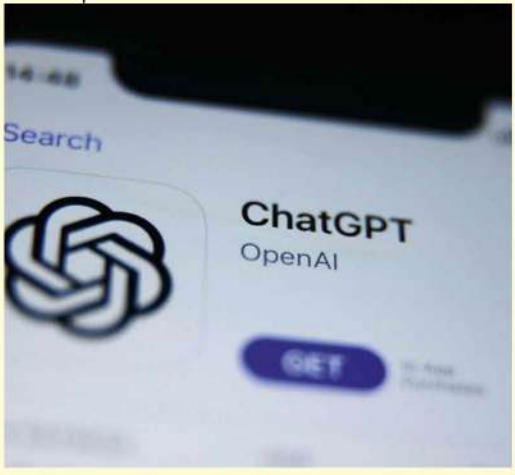
JULY
Australian researchers published a paper outlining a potential use for honey from the bizarre honeypot ant: creating powerful antibiotics. In doing so, they acknowledged the thousands-of-years-old medicinal use of the ant by Australia's Indigenous people.

AUGUST
After 25 years of research, a woman born without a womb became the first in the UK to have a successful womb transplant. The donated organ came from her sister. The patient hopes to have an embryo transfer procedure, after which she may be able to carry her own baby and give birth.

TECHNOLOGY & PHYSICS IN 2023

BETTER INTELLIGENCE

While ChatGPT was still enthralling first-time users, its creators, OpenAI, unveiled a major upgrade to the chatbot. Called GPT-4, the upgraded version allows users to input image prompts – not just text – and, apparently, is less likely to invent facts. The new model is currently only available to paid subscribers, while ChatGPT remains open to the public.



MIND READER

A machine that reads your thoughts became more science fact than science fiction, thanks to neurotechnologists at the University of Texas at Austin, in the US. The decoder is the first wireless and non-invasive machine to do this, using functional magnetic resonance imaging (fMRI) to measure the changes in blood flow around your brain – translating ideas into continuous, natural language.

ADDED DIMENSION

June saw the announcement of yet another AI project: Neuralangelo, a piece of software capable of generating lifelike virtual replicas of intricate 3D models, such as buildings and sculptures. Eventually, it could enable developers to import detailed objects into virtual environments like video games.

THEORY BECOMES REALITY

Fifteen years of theories and painstaking observations culminated in the discovery of the first evidence of low-frequency gravitational waves rippling through the Universe. The discovery could answer some of our biggest questions about how the Universe was born.

COMMENT

KIDS ARE THE KEY TO UNDERSTANDING OBESITY. BUT WE NEED MORE OF THEIR GENES

We can unravel the role that bodyweight plays in disease, but we need a bigger, more diverse, sample of genetic material to do so

When I was a young postdoctoral researcher at Cambridge in 2002, a colleague took me to a fancy dinner at Peterhouse College, the oldest of Cambridge's colleges.

It was a six-course affair and, rather ridiculously, you had to change seats (and hence dinner companions) for each new course. During the first course, an older, bearded professor sitting opposite me asked, "So young man, what do you do?"

I told him I was working on the genetics of childhood obesity.

"Ha! Do you know what your problem is?" he replied. "You give fat people an excuse."

The disgust in his tone threw me and as I mobilised all my diplomatic nous to gently push back, I was saved by a literal bell, signalling that we had to switch seats for course number two.

It occurred to me later that the professor's view was shared by much of society. Obesity is seen as a problem of physics; people just need to eat less and move more. But although *how* we get to our bodyweight is reliant on physics, the real question is why? Why do people behave so differently toward food? Why do some people respond to stress by eating more and others by eating less? Why do some people love food, while for others it's simply fuel?

Why, what, when and how much we eat have powerful societal and cultural underpinnings. But there are equally powerful genetic factors that influence our eating, and hence our bodyweight.

Large population-based studies, such as UK Biobank, a survey of nearly half a million adults, has helped to reveal the genetic architecture underlying differences in body size. For instance, we now know of over a thousand genes that are linked to bodyweight, and the vast majority are expressed in the brain and influence our eating habits.

What's intriguing is that, while there are overlapping genes, there are unique genetic signatures linked to developing obesity in childhood versus gaining excess fat as an adult.

But since UK Biobank is a survey of adults, the childhood obesity data was obtained by asking the participants: 'When you were 10 years old, compared to the average, would you describe yourself as thinner, plumper, or about average?'

This relies on memory, but most people do recall their body size as children. It is, however, still a blunt measure and crucially, misses out on factors such as rate of growth, illness and type of diet.

There are 'smaller' studies, such as the 14,000 participants of the Bristol-based Children of the 90s study, which provide rich data. But large samples on the scale of Biobank, which are required for the study of more nuanced characteristics in children, do not exist.

And that's a problem, because obesity is one of the leading public health problems we face, and we know that children with obesity overwhelmingly grow into adults with obesity. Thus, understanding the genetics and natural history of childhood obesity will play a key role in its treatment and prevention.

But there is hope. D-CYPHR is a genetics research programme led by the National Institute for Health and Care Research (NIHR) BioResource that's open to every child in the UK (bioresource.nihr.ac.uk/dcyphr). It aims to be truly inclusive and investigate a range of conditions, from mental health to cardiovascular disease and diabetes, for which obesity is a major contributing factor.

Inclusivity matters here, because, to date, more than 80 per cent of human genetic data comes from people of white Northern European descent. This means much of our understanding of human traits and diseases is limited by this skewed perspective.

People of different ethnicities have different risk profiles for different diseases, and understanding these improves our ability to treat and prevent those diseases… in everyone.

D-CYPHR is ambitious and will face challenges in creating a truly inclusive research sample. But if it does, it would circumvent many of the problems in adult health research by building diversity in from the beginning. For the first time we could track the bodyweight and health of an ethnically and geographically representative group throughout life, revealing how different environments interact with genetics to affect the development of obesity.

Improving the health of children – all children – must be a priority, if only because unhealthy children tend to become unhealthy adults.

PROF GILES YEO
(@GilesYeo)
Giles is a professor at the University of Cambridge, whose research focuses on food intake, genetics and obesity. He is a broadcaster and author, and his latest book is Why Calories Don't Count (£14.99, Orion).

"Why, what, when and how much we eat have powerful cultural underpinnings"

ILLUSTRATION: BERNARD LEONARDO

COMMENT

A DASH OF 'QUANTUM WEIRDNESS' ADDS AN INTRIGUING NEW ASPECT TO THE THEORY OF EVOLUTION

Just suppose survival of the fittest had a quantum element. What would that mean for life on Earth?

In 1990, while at Haverford College, I embarked on a transformative academic journey into biophysics – the captivating intersection of physics and biology.

It was during this time that I delved into the tantalising notion of quantum mechanics operating within living organisms.

Unbeknown to me, this exploration would etch an enduring imprint on my scientific voyage, kindling a lifelong fascination with biophysics. Ultimately, I charted my research course in quantum cosmology, but the echoes of biophysics persisted.

One of the most potent strategies in unveiling new truths in physics arises from principles that unify seemingly disparate phenomena. Einstein's principle of relativity, for instance, harmonised electromagnetism with the fabric of four-dimensional spacetime.

Similarly, physicists like Richard Feynman and Paul Dirac achieved remarkable feats by bringing together disparate principles, uniting quantum theory with relativity to birth a new perspective on the quantum field. This yielded predictions like the existence of antimatter and the Standard Model of elementary particles, which have since been validated at particle accelerators around the world.

During my tenure as a physics professor at Dartmouth College, I met Dr Salvador Almagro-Moreno, a remarkable molecular biologist. Over numerous intellectual exchanges, Salvador and I discerned a common thread weaving through our distinct fields: the potential for a symbiosis between physics and biology.

Our collaborative brainchild emerged by converging Darwin's theory of natural selection and the quantum superposition principle. This weaved the relentless engine of evolution into the enigmatic behaviour of quantum entities.

Darwin's theory of natural selection hinges on genetic variations, survival and reproduction. It favours organisms that possess advantageous traits, thereby propelling evolution.

Conversely, the principle of quantum superposition illuminates the peculiar ability of quantum entities, such as electrons or molecules, to exist in multiple states simultaneously – a concept that defies classical physics.

We christened our creation the 'bio-dynamic optimisation principle'. At its core, it asserts that living systems evolve to exploit any aspect of physics that enables exploration of all possible 'fitness landscapes'.

A 'fitness landscape' is a visual or conceptual representation in biology and evolution that shows

ILLUSTRATION: MATTHEW HOLLAND

"Our principle opens up promising avenues for exploration"

how the fitness, or success, of an organism depends on its genetic traits and how those traits interact with the surrounding environment.

It's essentially a map that helps us understand which traits are advantageous or disadvantageous for survival and reproduction in a specific environment. High peaks on the landscape represent traits that lead to greater fitness, and success, while valleys represent less advantageous traits.

This concept helps to explain how natural selection works and how species evolve. The idea may breathe new life into the role of quantum mechanics within the thermally dynamic environments of living organisms.

For example, consider the firefly. These luminescent insects rely on quantum transitions to generate light – a vital survival strategy. One might conjecture that the tumultuous milieu of biology would erode such delicate quantum phenomena. However, our bio-dynamic optimisation principle suggests otherwise.

It posits that natural selection acts as a vigilant guardian, preserving the quantum coherence essential for survival-related quantum activities, such as bioluminescence in fireflies. The quantum of life also appears to function in photosynthesis, allows birds to navigate and perhaps even influences the brain.

Our principle opens up promising avenues for exploration, for example: quantum-mechanical communication (living systems, such as a swarm of single-celled bacteria, may harness quantum communication for efficient signalling); quantum-enhanced sensing (organisms could leverage quantum phenomena to develop hyper-sensitive sensors for detecting subtle environmental changes); and quantum resilience (due to natural selection, some lifeforms may have evolved mechanisms to withstand quantum decoherence – the collapse of quantum properties when particles interact with their surroundings – ensuring the persistence of quantum advantages in the face of adversity).

Quantum engineers such as Prof Clarice Aiello of UCLA work on experiments that probe quantum mechanical effects. One goal of her research is to figure out how biology hacked quantum mechanics – information that could help engineers make a better quantum computer.

The fusion of Darwin's evolutionary wisdom with the enigmatic world of quantum mechanics hints at profound implications for the essence of life itself.

Perhaps the bio-dynamic optimisation principle and the field of quantum biology stand as a testament to the enduring allure of science, where unexpected connections and innovative ideas continually shape our understanding of the Universe and the miraculous wonders it holds.

PROF STEPHON ALEXANDER

(@stephstem) Stephon is a theoretical physicist specialising in cosmology, particle physics and quantum gravity based at Brown University, Rhode Island. He also explores the connections between music, physics, mathematics and technology.

COMMENT

THE UK'S COUNTRYSIDE IS IN TROUBLE... AND WE NEED TO DO MORE TO HELP IT

Britain's woodlands, wetlands and wildflower meadows are under threat. But awareness isn't enough to save them

The countryside. For me – in the rain-soaked, semi-industrial corner of the north of England that I call home – this term brings to mind rolling green hills peppered with sheep, and divided up by hedgerows and a delightfully chaotic maze of drystone walls.

It's an idealised scene, but one rocked by an uncomfortable truth: despite appearances, the UK countryside is an ecosystem in trouble. Serious trouble. Natural spaces, and the wildlife that depends on them, are in decline, according to the recent State of Nature report – a comprehensive review of plant and animal life across the UK produced by a collaboration of environmental non-governmental oranisations, academic institutions and government agencies.

In fact, almost 1,500 native species are now threatened with extinction. Plus, just 11 per cent of UK land is within protected areas, some of which aren't adequately managed for wildlife. The government has signed up to a global target of improving that figure, setting a goal of protecting 30 per cent of land for nature by 2030; the so-called '30x30' initiative. But sadly, nature doesn't respond to targets alone.

> **"Merely drawing lines around areas of outstanding natural beauty is not enough"**

Quite simply, many protected areas in the UK aren't up to ecological scratch, as stated in the Protected Areas and Nature Recovery report published in 2022 by the British Ecological Society. Pollution, the spread of non-native species and unsustainable farming practices continue to drive the loss of biodiversity within those boundaries. These include large amounts of pesticide use, the spread of monocultures and overgrazing leaving little wild space.

Crucially, the report stated that regions should only count towards the 30-per-cent target if their wildlife actually shows signs of long-term recovery. Merely drawing lines around areas of outstanding natural beauty isn't enough – a concerted effort is needed to monitor and understand their ecological value.

This will require money and resources. Prof Richard Gregory, the RSPB's head of conservation science, told me that to really tackle the drivers of nature's decline the figure will have to be "billions, not millions". Without that investment, however, the societal cost of allowing the environment to degrade will be greater.

So, what can be done? The fact that one of the biggest drivers is unsustainable farming raises a fundamental quandary: we need the land to produce food, but we also need it to sustain plants that clean our air, peatlands that lock away planet-warming carbon and insects that enrich our soils and pollinate our crops. The task for UK farmers, in a changing climate with a growing demand for food, is unenviable.

There's no question that agricultural methods need to change. All over the country, the Nature Friendly Farming Network is working to make more space for wildlife. That's a start. But some scientists argue that we need to take much more ambitious approaches. Prof Andrew Balmford from the University of Cambridge, who has spent 20 years studying how to reconcile food production with biodiversity, suggests a possible answer: a concept called 'land sparing'.

This basically involves restoring or creating habitats within existing agricultural landscapes, while adopting sustainable ways to boost food production in the areas that continue to be farmed.

So-called 'rewilding' projects have already had some dramatic effects. More than 600km² (150,000 acres) of the Cairngorms, in the Scottish Highlands, have been restored for woodland-dependent wildlife. Since 2019, the project has overseen the plantation of Scots pine trees and other native woodland, as well as the restoration of peatland and floodplains to encourage a return to a more ecologically viable state.

In the Knepp Estate in West Sussex, rewilding efforts over the last several years have seen a huge increase in critically endangered birds, such as nightingales, turtle doves, peregrine falcons, ravens, red kites, sparrowhawks and lesser-spotted woodpeckers.

Rethinking our towns and cities can also play a crucial role. According to the People's Trust for Endangered Species, simple measures to make gardens more 'hedgehog friendly', such as punching holes in the bottoms of fences to connect the gardens into a network of habitat, have helped stabilise and even boost numbers of the native mammals in urban areas.

Another study, carried out by researchers at the University of Bristol, has shown that city gardens and allotments can be hotspots for pollinating insects.

There's still so much more to be done. When it comes to our countryside, beautiful doesn't mean biodiverse. If nature is going to thrive – and we need it to – we'll have to start looking more closely.

VICTORIA GILL

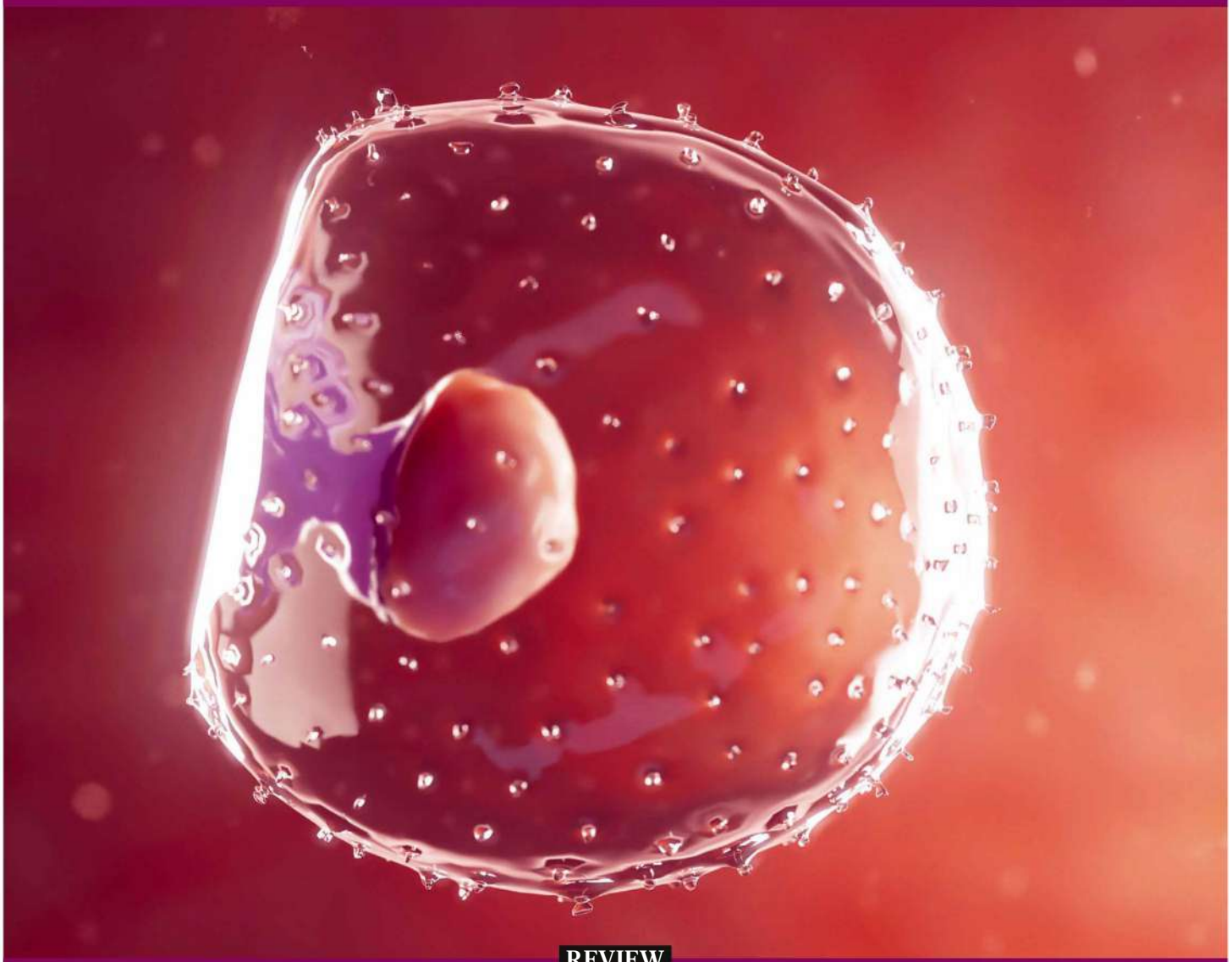
Victoria is BBC News's award-winning science correspondent. Her reporting can be found on television, radio and online.

ILLUSTRATION: DENIS FREITAS

REALITY CHECK

THE SCIENCE BEHIND THE HEADLINES

Embryo research | Indoor air pollution | Sad clown paradox



REVIEW

EMBRYO RESEARCH: WHY SCIENTISTS WANT MORE THAN 14 DAYS TO STUDY EARLY DEVELOPMENT

An extension to the 14-day limit on research has been proposed and has support. But there are moral and ethical questions to consider

"Scientists are keen to learn more about the so-called 'black box' of embryonic development: the time period between two and five weeks after fertilisation"

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Members of the British public surveyed by the Human Developmental Biology Initiative and UK Research and Innovation Sciencewise largely gave their backing to a controversial proposal recently. Of the 70 participants, most expressed support for extending the 14-day limit on the research of human embryos.

If a change to the law is successful, researchers will be able to grow and study cultured human embryos for longer periods of time. This subject has always raised moral and ethical concerns, but those in favour of the extension argue that it'll afford researchers unprecedented insights into human development, which could lead to significant improvements in fertility and health.

WHAT IS THE 14-DAY RULE?

In UK law, it's illegal to carry out research on laboratory-grown human embryos beyond 14 days of development. This includes 'spare' IVF embryos that have been donated for research purposes and embryos created with donated sperm and eggs.

Similar rules exist in other countries – such as the US, Japan, China and the Netherlands – but while some are legally binding, others are just guidelines. There are countries, such as Germany and Russia, which don't currently permit any human embryonic research at all.

WHY IS THE CURRENT LIMIT SET AT 14 DAYS?

At 14 days, the embryo is a small and simple structure, made of two layers of cells. There's no head or heart, brain or spinal cord, nor recognisable organs of any kind. The embryo is made of stem cells that have the potential to form specialised cell types, such as neurons and muscle cells, but this has yet to happen.

Unequivocally, the embryo can't think, feel pain or experience consciousness. The 14-day cutoff therefore helped to assuage those with moral concerns over the use of human embryo experiments. "It was always an arbitrary limit that enabled some research to go ahead in the face of what was strong opposition at the time," says Prof Robin Lovell-Badge, head of the Stem Cell Biology and Developmental Genetics Laboratory at the Francis Crick Institute in London.

When the current law was established in the UK in 1990, researchers were just starting to learn how to culture human embryos. They could grow them for up to a week, but after that the embryos all failed. The idea of reaching 14 days seemed unachievable, so setting that as the limit was regarded as a safe bet.

WHAT'S CHANGED? WHY DO SOME RESEARCHERS WANT TO REVISE THE RULE NOW?

In 2016, scientists from the UK and US managed to grow human embryos in the lab for 13 days after fertilisation. This was the longest time period ever recorded – and the embryos probably could have been grown for longer, but the researchers obeyed the law and stopped their experiments. The formerly unachievable 14-day limit had been proven to be within reach.

Then earlier this year, scientists at the University of Cambridge announced that they had made the first 'synthetic embryos' (or 'embryo models'), which are embryo-like structures made from stem cells. They are not embryos – they require no involvement of sperm and egg, and so no fertilisation – but are a lot like them. Scientists are already using them to learn more about human development, fertility, health and disease.

WHAT DO RESEARCHERS WANT A NEW LIMIT TO COVER?

Scientists are keen to learn more about the so-called 'black box' of embryonic development: the time period between two and five weeks after fertilisation. At this stage, the embryo becomes a multi-layered structure containing specialised cells. It gains a rough body plan in the form of a top and a bottom, a front and a back, and a left and a right. Rudimentary organs, such as the heart, kidneys and gut, begin to form.

Yet researchers know little about this process, known as gastrulation, because they have never had access to human embryos during the 'black box' age.

DO ALL SCIENTISTS WANT AN EXTENSION?

"Within the field, I think the majority of scientists would like to see the 14-day rule extended," says Lovell-Badge, who also chairs the International Society for Stem Cell Research Guidelines Update Task Force and works closely with scientists in the field. For researchers who argue against the extension, however, a key concern is that the proposal could backfire and lead to restrictions →

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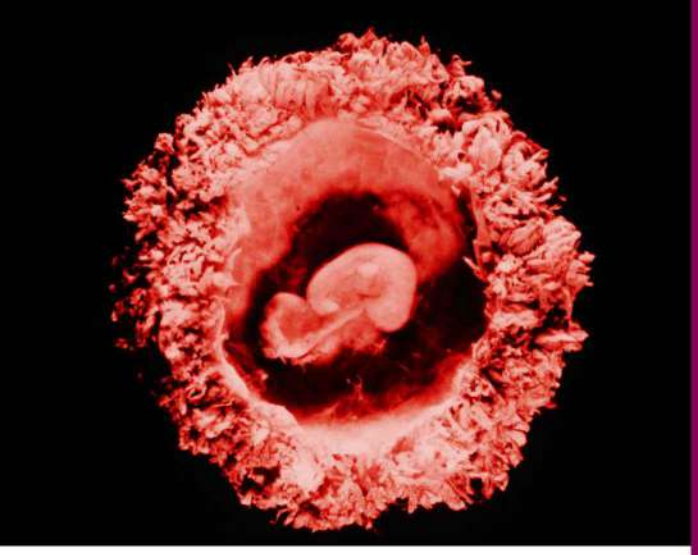

ABOVE Scientists are now able to make 'synthetic embryos', which may reduce experiments on cultured human embryos

→ that will make embryo research more, rather than less, difficult. This could jeopardise future studies into human embryonic development beyond the well-researched 14 days.

Then there are other groups outside of academia, such as Right To Life UK, who oppose any experimentation on human embryos.

WHAT COULD SCIENTISTS LEARN?

Spina bifida is a birth defect that occurs when the neural tube starts developing, but doesn't finish forming correctly. Its origins lie somewhere in the 'black box'. If scientists could study this event in cultured human embryos, they may be able to devise new ways to prevent or treat the condition.

The same goes for a number of congenital abnormalities. We know that taking folic acid when pregnant reduces the risk of spina bifida. There could be other dietary supplements that reduce the risk of congenital disorders of the heart and other organs. Extending the 14-day limit will help scientists to work this out.

Extending the limit could also help those with fertility problems. The success rate for IVF is just one in three, with many embryos failing around the time of gastrulation, and many miscarriages occur about this time too. Studying gastrulation directly could enhance our understanding of why the process can go wrong. Another possibility would be improving fertility techniques, such as mitochondrial donation (using healthy energy-generating structures – mitochondria – to correct faulty versions in eggs or early embryos).

Scientists know that the synthetic embryos are similar to regular human embryos, but because no one has been able to study the 'black box' of normal embryonic development, it's impossible to say if they mimic this part well or not. If they do, then scientists could end up using fewer normal human embryos.

by **DR HELEN PILCHER**

Helen is a science writer with a PhD in cell biology. Her most recent book is How Nature Keeps Time *(Bloomsbury, £16.99).*

ANALYSIS

INDOOR AIR POLLUTION: HOW COOKING CAN DAMAGE YOUR DNA

From roast dinners to scented candles, there are potentially harmful pollutants lurking in every home

Every year, there are questions and comments about the undesirable health effects that result from the festive tradition of roasting giant pieces of meat. Most of us, however, probably think these centre on what they can do to our waistlines, instead of our DNA by breathing in what our ovens are pumping out.

As recent research from Denmark has highlighted, cooking – particularly roasting – and the burning of candles can damage your DNA. It's a study that adds to a growing body of science examining the effects of indoor air pollution that comes from a huge number of sources.

So, what are these contributors to poor air quality, and what can we do about them? According to Nicola Carslaw, professor in indoor air chemistry at the University of York, there are a lot of chemicals that could be a problem. In fact, a recent project she was involved with counted more than 900 substances of concern. "Obviously, you can't possibly think about 900 different chemicals in your average home," she says. "So probably the most sensible way to do it is to think about sources."

There are certainly a lot to consider, with everything from painting and decorating products, kitchen and bathroom cleaners, and beauty products like nail varnish possibly containing these chemicals. Burning fuels in hearths or on stoves and candles produce one of the main types of pollutant: particulate matter, which is a mixture of dirt, soot and chemicals all stuck together.

Then there are volatile organic chemicals (VOCs). These are a large group of airborne chemicals that can be released from building materials and new furniture, as well as from cooking and consumer products. And, of course, outdoor pollution can always creep inside.

Cooking generates a lot of particle emissions, which come, as in a car engine, from burning fuel – like when you use a gas hob – and from frying meat in oil, for instance. In developing countries, a widespread use of fuels like kerosene (paraffin) and coal for cooking takes a massive toll on people's health.

The World Health Organization estimates that each year 3 million people die prematurely as a result of cooking emissions that increase the risk of serious health problems, including heart disease, stroke and lung cancer. "It's a very different problem in some

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"Cooking generates a lot of particle emissions, which come, as in a car engine, from burning fuel"

countries," says Prof Carslaw. "And it's probably more to do with the fuel that they're burning, rather than the cooking per se."

By comparison, people living in European countries tend to cook in a relatively clean way, but are still exposed to emissions from the heating and cooking of the food itself. Due to limited research, it's extremely difficult to understand how harmful these are in relation to, say, traffic emissions.

It's worth pointing out that this doesn't mean you should be forgoing the Christmas turkey. Having one big cook-out, or lighting a candle occasionally, are not enough to worry about. But the recent study, led by Karin Rosenkilde Laursen, a post-doctoral researcher at Aarhus University in Denmark, offers new insights into how cooking and candles might affect health.

ABOVE Preparing a regular roast dinner can raise the levels of proteins linked to inflammation of our airways

With her co-workers, Laursen asked people with mild asthma to sit in a closed chamber for five hours, either in clear and filtered air or while emissions were funnelled in from a connecting chamber where pork was roasted in an oven or candles burned. The results show that both cooking and candles – while producing different sizes of particles and types of chemicals, which may influence their precise effects – raised levels of proteins associated with inflammation of the airways.

Laursen notes that cooking, particularly, has an effect on DNA. "We saw that when exposed to cooking →

ABOVE A flickering candle produces more particulate matter, and therefore more potentially damaging emissions, than a still flame

→ emissions, people actually had DNA damage," she says, explaining that this can be associated with cell repair processes that trigger cancer-causing mutations. "So, it's not that we observed cancer or even cancer pre-stages, but we observed this DNA damage, which may, at some point in the long run, lead to mutations that lead to cancer."

As for the participants sitting in the clean, filtered air, some of their inflammation markers actually went down. This seems to suggest that many of us are faced with such a constant bombardment of chemicals that our levels are always slightly raised.

When it comes to what we can do to reduce indoor air pollution, Prof Carslaw's approach is "ventilation, moderation, education". By ventilation, she means opening windows and using cooker hoods that extract and eject the harmful emissions (noting that some vent them back into the kitchen).

Moderation is about considering how often we use, for example, things like scented candles or harsh cleaning products like bleach. First, though, should come education: while the harmful effects of air pollution are well recognised for the outdoor environment, it's not the case for the indoors.

No one is suggesting we should switch to takeaways to keep cooking emissions down, but we could modify how we cook and deal with inevitable emissions. For example, cooking meat with lots of fat at high temperatures can be more harmful than boiling pasta. As Laursen points out, though, "You should eat varied foods, so I keep on cooking all the foods, but I just use my cooker hood every time and then air out afterwards."

With Christmas around the corner, she offers a final tip for those who enjoy advent candles: a flickering flame indicates increased particle production, so place it where it burns steady and doesn't waver.

by **HAYLEY BENNETT**

Hayley is a science writer, based in Bristol, UK, who specialises in biology, chemistry and the environment.

COMMENT

SAD CLOWN PARADOX: WHY TEARS OFTEN LIE BEHIND THE LAUGHS

Mental health issues are common among comedians and performing is just one way they can self-medicate

When the news broke of the tragic passing on 28 October of the comedy actor, and everyone's sarcastic favourite in *Friends*, Matthew Perry (right), the tributes didn't focus solely on his talents for making people laugh. Featured prominently in the obituaries were his struggles with mental health and addictions to alcohol and painkillers, something the man himself would undoubtedly have approved of given his openness on the subject.

Perry wasn't unique in this. Many comedy icons – Robin Williams and Spike Milligan spring most easily to mind – are well known for their mental health struggles.

Such talents lend themselves to the 'tears of a clown' cliché, a concept best illustrated by the old punchline delivered when a depressed patient goes to see a doctor. The physician advises them to go and see the famous clown Pagliacci to lighten their spirits, only for the patient to burst into tears and reply: "But Doctor, I am Pagliacci."

Why would people so gifted at making others laugh be prone to struggle with their own happiness? Some surprisingly logical explanations can be offered by the workings of the human brain.

Humans are extremely social creatures: our brains experience pleasure when others approve of us, and pain if we're rejected socially. A low social status is reliably linked to mental health issues, like depression and anxiety.

Establishing cause and effect can be tricky, so it's hard to argue that those with poorer mental health often struggle to gain the approval of others. But one factor fundamentally intertwined with human interaction and acceptance is humour. Making others laugh is a reliable, efficient way to get people to like you.

Logically, this could mean that, to gain acceptance, those with mental health issues are more predisposed to resort to – and become adept at – humour.

A great deal of comedy is derived from observing, and commenting on, the more illogical aspects of human culture and behaviour. Most people are less likely to notice such things, because if everyone tends to agree that something is normal, our brains will more readily just accept it. It's those with an 'outside' perspective who'll have an ability to look at something common, and say, "That's actually funny, and here's why."

It's not just the 'tears of clown' cliché, either. There's also the 'tortured artist': a talented creative type capable of

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"The positive connection established between a comic and their audience is both transactional and transient"

works of supreme beauty, but plagued by inner torment and 'demons'. Vincent van Gogh would be the go-to example, but other artists who could have this label fairly applied include Edvard Munch, Jackson Pollack and Kurt Cobain. While there are many factors that contribute to becoming a 'tortured artist', research suggests that mood disorders and creativity are linked.

Perhaps the internal disruption that upsets mood and emotion in the brain extends mechanisms that regulate creative output. Or maybe the intense and atypical emotions wrought by a mental health issue compel the individual to find some way to express them by any means necessary. After all, communicating emotions is something our brains are wired to do.

Of course, not every individual who struggles with mental health is a socially awkward introvert. Many can, and do, enthusiastically engage with others around them. If you combine that with creativity and an 'alternative' perspective, then you've got the fundamentals of a great comedian.

Perhaps most important of all, if you struggle with mental health issues, comedy and humour can help make you feel better. While it may strike the average person as a nightmare scenario, for someone already feeling shunned and rejected, performing in front of an audience can mean you feel appreciated, accepted and even in control.

These are all things our brains respond positively to and it's all too easy to see how this could prove intoxicating for those who find the acceptance of others hard to come by.

Unfortunately, unlike 'normal' interpersonal relationships, the positive connection established between a comic and their audience is both transactional and transient – meaning they'd need to keep performing to maintain it.

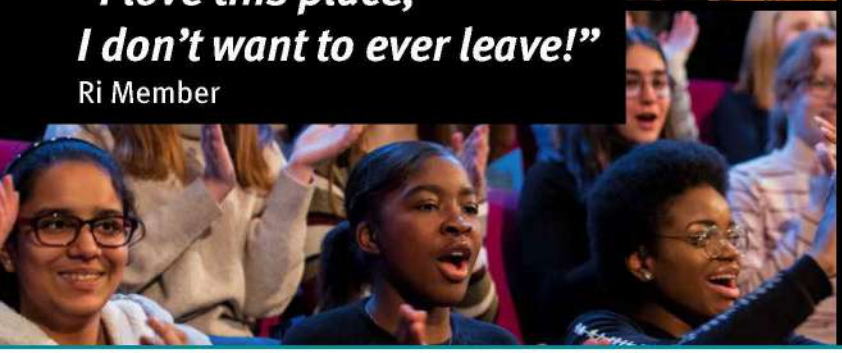
What's more, this 'self-medication' can manifest in darker ways. The comedy world is, after all, often one of late nights in bars and clubs among others who dwell in similar headspaces. The exposure to drink and drugs is pretty much unavoidable, which helps to explain why so many comedians have grappled with such things.

This is not to say that all comedy performers are social outcasts constantly battling mental health issues. You can be a successful comic without any of these things. But the comedy world is more accepting of such people than most. Indeed, you could say it rewards them. As a result, you could logically expect to see more clowns who are crying on the inside. SF

by **DR DEAN BURNETT**

Dean is a neuroscientist and occasional comedian. His latest book Emotional Ignorance *is out now (Guardian Faber, £14.99).*

"I love this place,
I don't want to ever leave!"
Ri Member



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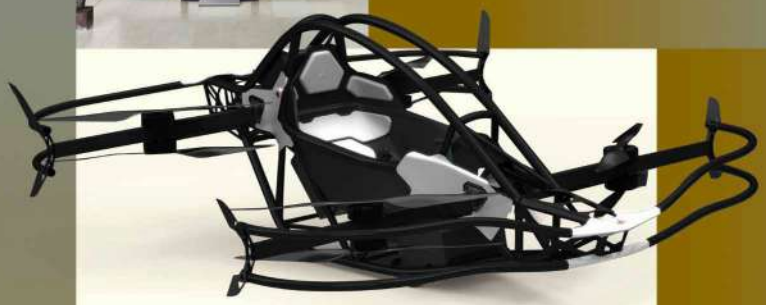
HOW TO CHRISTMAS SHOP LIKE A BILLIONAIRE



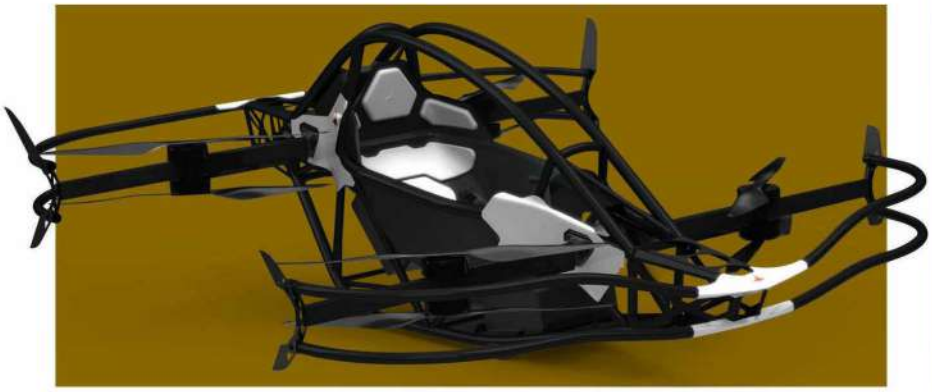
If we were all billionaires, Christmas would look very different. While we would love to buy our loved ones diamond chess sets and trips to the Moon, our sights are set on more modest gifts. But who says we can't dream? So this year we've picked our favourite 'money is no object' gifts... and some more realistic alternatives

A PRIVATE AIRCRAFT

EXPENSIVE

Let's be honest, cars are old news. Sure, you could live the super-rich life in a new Tesla or a classic supercar, but they're too familiar to really turn heads. What *would* turn heads (or rather, tilt them upwards) is your own personal eVTOL (electric vertical take-off and landing) aircraft, such as the Jetson ONE. It's an impressive feat of engineering, even if it does look like a gaming chair with propellers. And you don't actually need a pilot's licence to fly it, since an on-board computer is doing a lot of the heavy lifting, aviation wise. It's classed as an ultra-light aircraft, however, so it can only be used recreationally. That means only flying it in your vast back garden, not over public areas.

Jetson ONE, $98,000 (approx £80,000)
Jetsonaero.com



AFFORDABLE

As much fun as a personal eVTOL would be, there are cheaper and safer ways to take to the skies. In recent years, drone technology has advanced significantly, driven heavily by DJI. One of the latest drones from the company is the Avata. A first-person-view drone, it comes with a pair of goggles that allow you to see Avata's view of the world. It can speed through the sky, flip, dive and move in a way that birds would envy. Sure, *you're* not actually flying, but that doesn't diminish the thrill on offer here. Prices start at £499 and even at its most expensive (£1,249), it's a bargain compared to the Jetson ONE.

DJI Avata, from £499
DJI.com

A FOOTBALL TEAM

EXPENSIVE

Buying a football team is the trendy thing to do, if the likes of David Beckham and Ryan Reynolds are anything to go by. So why not join in the fun? Major teams can cost billions, but smaller teams can make great 'stocking fillers'. And nothing says 'Merry Christmas' quite like the stress of becoming the new manager of a rapidly declining football club facing the threat of relegation.

Buy a football team, from £500,000
Mergerscorp.com

AFFORDABLE

If you're looking for a less costly, more relaxed football management experience, try *FC 24*. The football game is available on all major consoles and offers the latest in graphics and gameplay. Owning one real club costs a fortune; owning all the clubs in digital form costs just £69.99, plus there are no pundits, agents or fans to deal with.

EA SPORTS FC 24, £69.99
EA.com

GETTY IMAGES

AN UNRIVALLED AUDIO EXPERIENCE

EXPENSIVE

The Sennheiser HE 1 isn't for the average person, because what average person drops £54,000 on a pair of headphones? Let alone a pair that can't be separated from their gigantic amplifier (complete with glass tubes and a solid marble base). Not the headphones to buy for someone who listens to music during their commute on pubic transport, then.

Sennheiser HE 1, £54,000
En-uk.Sennheiser.com

AFFORDABLE

The Sony WH-1000XM5 don't come with a marble base or glass tubes. But they are a great pair of headphones. They're Bluetooth enabled, have market-leading noise cancellation and a 30-hour battery life. Best of all, they don't cost £54,000. Sure, they're still pricey at £380, but if there's a music lover in your life, these headphones will be an investment they'll love for years.

Sony WH-1000XM5, £380
Sony.com

AN OUT OF THIS WORLD WALLET

EXPENSIVE

Bejeti's Planetesimal wallet is made from metal extracted from a meteorite and costs $29,500. Can it hold a lot? Not really – there's only room for three cards. Is it light? No, it's all metal. Will it make you look like an evil CEO stealing money from the poor in a dystopian cyberpunk future? Actually, yes. And just imagine the kudos you'll get from the cashier when you whip this out in Tesco.

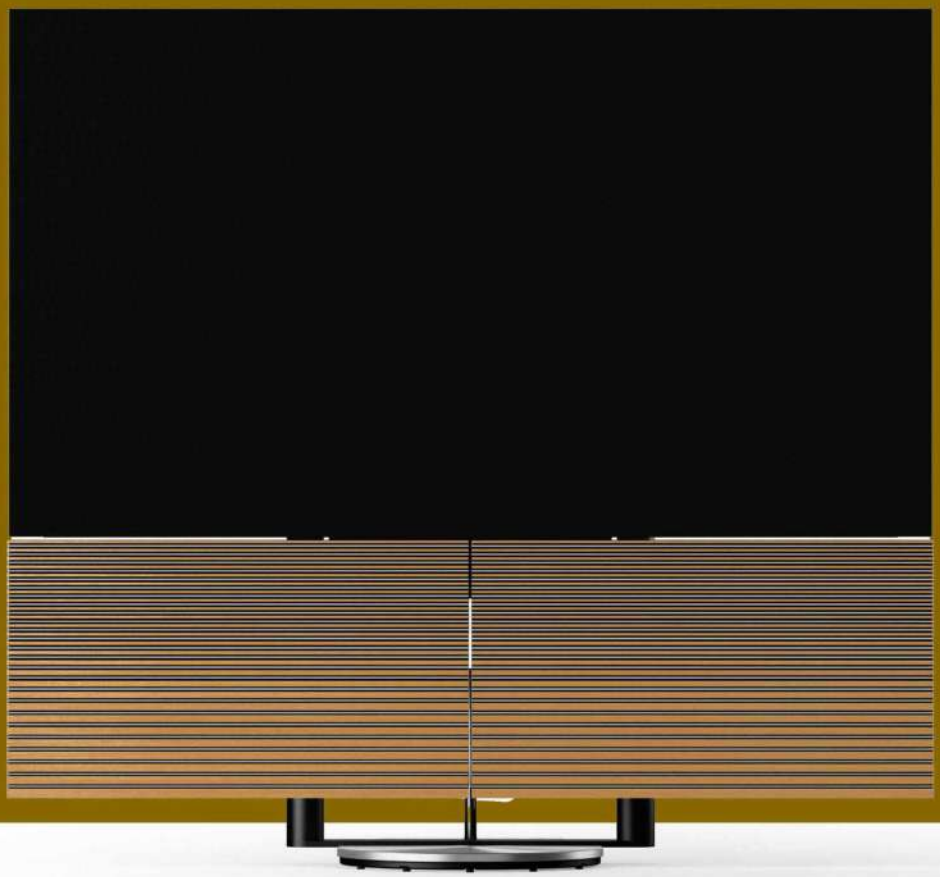
Bejeti Planetesimal, $29,500 (approx £24,000)
Bejeti.com

AFFORDABLE

At £85, the Bellroy Hide & Seek wallet is still expensive, but not quite meteorite-metal expensive. The luxury leather wallet has RFID protection, space for up to 12 cards and a hidden section for your notes and coins. The Bellroy Hide & Seek might not be made of materials from outer space, or be one of a limited edition collection, but it's a nice, practical wallet at a price that's not out of this world.

Bellroy Hide & Seek, £85
Bellroy.com

AN EXTRAVAGANT TV



EXPENSIVE

Surround sound, 4K, Ultra-HD… these things don't impress people now. For a TV that says opulence, you need spectacle, and B&O has you covered with the Beovision Harmony. It comes in a host of sizes, although anything below the maximum 97-inch option just isn't going to be extravagant enough. But sheer size isn't this TV's only extravagance. It also reveals itself from behind its grilled wooden panel… every single time you want to use it. The panels split and rotate apart, almost like a pair of theatre curtains, to reveal the headline act for your evening's viewing. (Even if it's *I'm a Celebrity…*) That wooden panel also contains a pair of speakers blasting B&O's signature sound quality. Needless to say, such theatrical levels of extravagance come at a hefty price.

Beovision Harmony, £50,450
Bang-olufsen.com

AFFORDABLE

B&O's Beovision is more art project than TV, pushing the boundaries of both TV design and your wallet. But few of us really need to spend that much money for a unique TV experience. If you want a TV that's just as clever, but won't leave you feeling like you've been robbed blind, consider the Sky Glass. It's stylish, it's sleek, it has its own built-in soundbar and it's voice activated. It also doesn't cost the Earth, starting at £699. With all the money you're saving, you can even add Sky Live – an interactive camera for video calls, workouts and games. The Glass might not have the theatrics of the Beovision, but it does offer all of the same features (and more) for tens of thousands less.

Sky Glass, £699
Sky.com

A REAL-LIFE TRANSFORMER

EXPENSIVE

What do you get the person whose garage is filled with Ferraris and Lamborghinis? Boring friends will tell you to get them another supercar. Cooler friends will tell you to get them a $3 million, 4.5m (14.8ft) tall robot that *transforms into a car*. It can be piloted via a cockpit crammed with controls and displays, and its two giant arms can lift, crush and move massive objects. So it'd probably be useful in the garden.

Archax, $3 million (approx £2.4m)
Tsubame-hi.com

AFFORDABLE

Handbag dogs are so last year. This year its all about palm-sized cyber hounds, such as Petoi's Bittle robot dog. Well, not exactly. Although Bittle would make a great gift for anyone with a budding interest in robotics. They can build the robodog, then program it to do flips and tricks while learning the basics of coding. Better still, it's a dog that you'll never have to house train.

Petoi Bittle, £259.99
Petoi.com

A FANCY COFFEE MACHINE

EXPENSIVE

Do you know someone who likes their coffee to be as strong as jet fuel? If you do, and you've got a spare £17,000 lying around, you can get them a jet engine to make it with. Okay, so it isn't actually a real jet engine, but a scaled-down replica made of aviation-grade aluminium. It even has spinning blades. It doesn't make any speciality coffees, though. Or grind coffee beans, or froth milk. But if you're looking for a gift for someone who favours form over function…

Aviatore Veloce Turbojet, £17,000
Superveloce.co

AFFORDABLE

If your coffee-drinking friend prefers regular coffee (without the jet engine flourish), there are plenty of coffee machines to choose from. The De'Longhi Stilosa machine costs £126, and not only will it brew coffee, but it also froths milk (so cappuccinos are back on the cards). Plus, it comes in a variety of colours to match your kitchen décor. Is it as interesting as a jet engine? No, of course not, but it's certainly a whole lot more practical, not to mention much easier to wrap.

De'Longhi Stilosa, £126.99
Delonghi.com

A QUARTER PAST RICH

EXPENSIVE

Nothing says you've got money to burn like a watch you can't read and costs as much as a house. The see-through casing on the Girard-Perregaux Quasar Azure Tourbillon may show all the intricately crafted inner-workings, but it also makes it extremely hard to tell the time. But then this timepiece isn't so much about making sure you're not late, as making it clear to everyone that you're considerably richer than them.

Girard Perregaux Quasar Azure Tourbillon, £289,000
Girard-Perregaux.com

AFFORDABLE

What CASIO lacks in luxury, it makes up for in affordability and, in this case, retro styling. The A163WA-1QES offers nostalgia for a time that feels far less chaotic. When stacked up against the Tourbillon, it's hard to see where the CASIO loses out. Sure, it might not be as fancy, but it's £288,967 cheaper, has a backlight, an alarm, a stopwatch, and it won't cause you to lose your mind if you misplace it.

CASIO A163WA-1QES, £32.90
Casio.co.uk

A LIFETIME'S MEMORIES CAPTURED FOR POSTERITY

EXPENSIVE

Would your life make a great movie? Maybe so, but you could never commission it yourself – that's not a good look. But if you were to drop hints to loved ones that, what you'd really like this Christmas is a feature-length film about your life and its effect on the world, that's much better. Then they can get the Narrative Trust to interview your friends and family, and delve into your life to create the movie. Narrative Trust has made films about the lives of some of the most important people in the world, so yours is bound to be just as good.

Narrative Trust film, $150,000 (approx £121,000)
Narrativetrust.org

AFFORDABLE

Instead of a feature film to tell someone's life story, what about a nice scrapbook instead? It'll be more personal and won't make the recipient feel as guilty about getting a £120,000 movie when they only got you socks. There are plenty of nice physical scrapbooks to buy these days, but there are equally nice digital options, such as Amazon's Echo Show 8, which will cycle through photos, creating a highlight reel of your loved one's life.

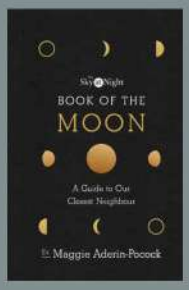
Amazon Echo Show 8, £59.99
Amazon.co.uk

A TRIP TO THE MOON

EXPENSIVE

Sure, you could rent a nice villa in Europe or splash out on a yacht, but when you've got billions in the bank you really need to up the ante when it comes to holidays. So how about a trip to the Moon? Yes, it'll cost north of £150 million and you won't actually land on the Moon, just fly around it, but the trip will put you in a very elite club. And that's priceless.

Trip to the Moon, Up to $150 million (approx £120 million)
Spaceadventures.com



AFFORDABLE

The Sky at Night Book of the Moon

If you decide £150 million could be better spent elsewhere, you can still experience the Moon with a good book. Granted, a book isn't quite as adventurous, but there are benefits here. Besides the much more affordable price, it won't require you to be strapped to a giant firework.

The Sky at Night: Book of the Moon, £12
amazon.co.uk

A CHESS SET WORTHY OF A KING AND QUEEN

EXPENSIVE

Why not lavish the chess enthusiast in your life with the world's most expensive set? "[The Pearl Royale's] decadence is symbolic of how I value the game itself," says its maker Colin Burn. "I love how chess brings people together from all societies, cultures and backgrounds." (An interesting view given how few people can actually afford this set.) Assuming, the board accounts for about $2 million of its value, that would make the 32 pieces worth around $62,500 *each*, so for goodness sake, don't lose. There are so many diamonds that anyone who sees the pieces will be immediately blinded by your wealth.

Pearl Royale, $4 million (approx £3.2 million)
Firstclasschess.com

AFFORDABLE

You don't need to plaster a chess board in diamonds to make it cherishable. In fact, beautiful wooden chess sets can be bought for less than £100, leaving you with a couple of million to spend on… other things. This classic set from established chess designer Regency Chess can be folded up and taken wherever you feel like having a game. Each piece is hand-crafted and finished with a clear polish, for an understated and refined look. Is it the world's most expensive chess set? It's not even close, but it comes with extra kings and queens in case you happen to lose one – talk about good value.

Deluxe Hardwood Folding Travel 14 inch Chess Set, £86.99
Regencychess.co.uk

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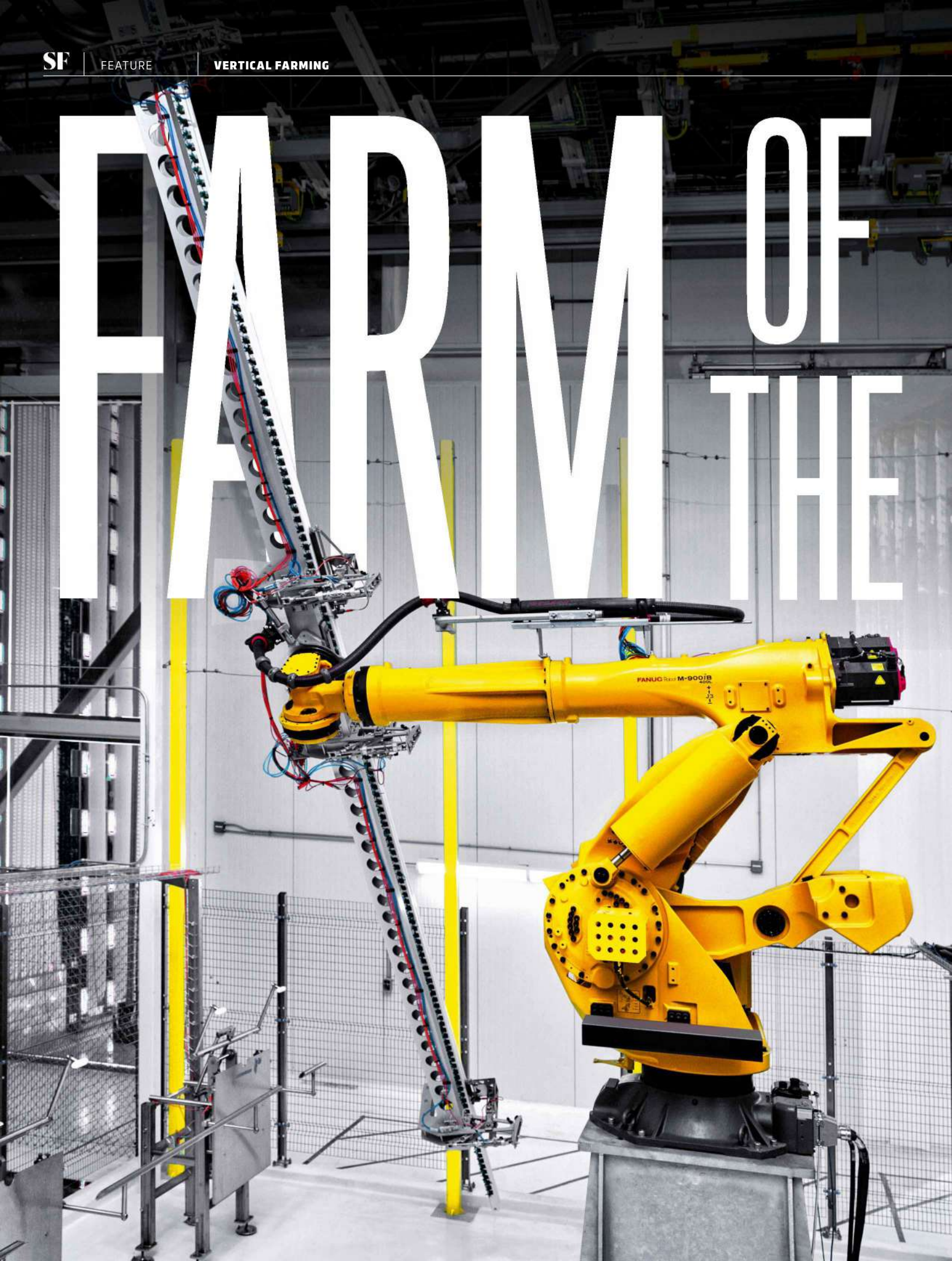


Join the BBC's *Planet Earth III* film crew and go behind the scenes in the city farm that's transforming fields into towers and running almost everything with robots

by CERI PERKINS

BBC ONE

Find out more about vertical farming by watching **Planet Earth III**

FUTURE

PLENTY UNLIMITED X2

PLENTY UNLIMITED X2

tepping through the heavy, air-locked door into the world's most advanced indoor vertical farm, it's the noise that hits you first. It's loud. Machines buzz and whir over the insistent drone of the warehouse-scale air circulation system.

The lights are dazzling. Peering up at the two-storey-high living curtains of plants quickly prompts a protest from your neck. Nearby, a few workers, wearing coveralls, hair nets, hard hats and earplugs, keep a cool eye on their busy robot underlings. The air is bright with the fresh, sweet scent of tender young salad leaves.

It's a far cry from the story-book picture of a farm; there's no mud, no wellies, no hens pecking in the yard. But the owners of this facility, a San Francisco-based company called Plenty, claim the system they're pioneering inside this warehouse in Compton, Los Angeles, can produce up to 350 times the yield compared to a field of the same size. What's more, they say their system uses just 10 per cent of the water and zero pesticides – and that it can be replicated almost anywhere.

The new farm in Compton grows four types of leafy greens: baby rocket, crispy lettuce, baby kale and curly spinach, and has the potential to produce up to 2 million kg (4.5 million lbs) of food annually, in the space of a single city block. If it lives up to its promise, the approach could revolutionise the way humanity feeds itself. That's why the crew filming the 'Humans' episode of *Planet Earth III* was on site a day after the farm began operating, so that audiences around the world could see for themselves.

The episode takes an unflinching look at the effect our species is having on the planet. "The biggest challenge facing the natural world from the human world, right now, is habitat loss," explains producer-director Fredi Devas. "And the biggest area of habitat destruction comes from agriculture."

Today, half of the world's habitable land is used for farming. More than three-quarters of that is used to rear animals, yet meat and dairy make up only around a third of the world's protein supply and provide less than a fifth of its calories.

As the world's population grows, our supply of cultivable land is dwindling and we're encroaching further into other species' homes. We urgently need to figure out how to keep up with the increasing demand for food. Do vertical farms like the one at Compton hold the key?

FROM SEED TO SHOP

At Plenty's Compton farm, every step of the process, from seed to shipping, is automated. From the moment that a worker tips a bag of seeds into the drum of the seed-sowing machine, the machines take over.

First, the seed-sower drops seeds into trays filled with a soil-free coconut husk substrate. The trays are sprinkled with water and whisked away on a conveyor belt for a two-day stint in a darkroom, where they're kept in humid conditions to encourage the seeds to germinate.

Once the seedlings emerge, the trays are sent to a vast propagation room. Here, the baby plants spend a couple of weeks stacked in horizontal racks, bathed in a carefully curated spectrum of LED light and receiving a bespoke cocktail of nutrients that kick-start the

growing process. Within two weeks of being sown, the young plants have a robust set of first leaves and their roots have wound their way down through the substrate, forming neat little plugs.

A bank of white robot arms, each fitted with a row of pincers, are surprisingly gentle as they pluck the plants and their plugs from their trays. In unison, the arms turn and nestle the plants into evenly spaced holes along a skinny 10m (32ft) section of metal track. Except this isn't a track, it's a tower – a fact that suddenly becomes clear as an enormous yellow robot arm grabs it, swings it through 90° and hangs it from the ceiling.

From here, the tower trundles down a corridor to the grow room, where it'll spend the next couple of weeks under precisely controlled light, water and nutrient conditions, gradually advancing along the runners as each of the towers ahead of it is taken off for harvest. By the time it reaches the →

ABOVE Once the plants are ready, a robotic arm fits them into a tower and hangs it from the facility's ceiling
BELOW Seeds are lightly watered before being transported to darkroom where conditions are optimised to promote germination

→ front of the queue, it's brimming with plush green leaves.

Down another corridor, in the harvest room, a robot arm unhooks the tower and lays it flat before zipping it through a set of rotating blades.

The harvested leaves tumble through an advanced optical sorting machine, which uses AI and special wavelengths of light to check each leaf for damage. Any that don't make the grade are popped off the conveyor belt and into the waste pile by a targeted puff of air. The rest are packaged on the spot; since they've never been in contact with soil, pesticides or human hands, there's no need to wash them.

The produce harvested here is trucked five minutes down the road to downtown Compton's Walmart, or to Wholefoods stores around Los Angeles. Plenty's greens go from seed to shelf in little more than four weeks – less than half the time it typically takes for the same products grown outdoors. And because everything about their environment is controlled, they can be grown year-round, at peak-season quality.

BRIGHT LIGHTS

Vertical farming isn't new. The idea of maximising a given footprint of land's growing potential by stacking plants indoors was developed in the early 2000s by Columbia University professor Dickson Despommier and students in his medical ecology class. Since then, hundreds of start-ups and investors have attempted to turn the concept into a viable, scalable method of food production, but none has succeeded.

"Number one, they had the wrong architecture," says Nate Storey, co-founder and chief science officer at Plenty. The artificial lighting that plants need to grow indoors without sunlight produces heat. A lot of it. The brighter the lights, the more heat they produce. Growers have struggled to protect their stacked plants from the heat rising from the layers below and found the cooling costs of vertical farming crippling.

The seed for Storey's big idea was sown more than 20 years ago, as he tinkered with organic systems at the University of Wyoming. One of his trials involved testing how well plants would grow in towers. "At a plant level, the performance was terrible," he says. "But on a square foot production basis, the performance was very high. And I thought: there's something to this."

The beauty of truly vertical architecture is that air can circulate freely, allowing natural convection to carry heat up and away, rather than trapping it between horizontal shelves. That switch means Plenty can use powerful LED lighting that mimics the Sun. "We're able to put three, four or five times as much energy into the space as someone else can, which means we get three, four, five times as much energy out for every dollar of hardware in the facility," says Storey. That "energy out" is the energy the plants use to grow. Five times the energy in; five times the yield.

The facility at Compton is the culmination of more than nine years of research to optimise every possible aspect of the process and the product, from flavour to crunch. The facility opened on 18 May this year and the *Planet Earth III* crew was there to film it.

But persuading a company to let you fly drones around millions of dollars' worth of brand-new equipment is a tall order. The negotiations took six weeks, with Devas's proposal going in front of Plenty's board at least twice. What swung it was a video Devas sent over of the man they had in mind for the job, world-class drone operator Zach Levi-Rodgers, flying drones at breakneck speed in and out of equipment in a gym. "I think from that they understood. 'Okay, if he can do that…' It put their minds at ease," says Devas.

Unusually, for wildlife filmmaking, it was easy to capture smooth, gliding ground shots, thanks to the level floors. But there were new challenges to contend with, including figuring out which camera settings would prevent all the frequencies of light on the farm causing the images to flicker.

To meet the farm's strict food safety standards, four crew members spent an entire day pre-shoot sterilising each piece of equipment: trolleys, gimbals, sliders and rigs, nine cameras, and every last lens cap and screw. On the day of the shoot, they suited up like the farm workers, donned gloves, shoe covers and goggles, and finally stepped through the air-locked door. "It really genuinely felt like a vision of the future," says Devas. "It was very strange to see these towers of produce just moving, with no-one around."

Of course, they couldn't leave without tasting the goods. "I grow my own food, totally organically, on my allotment," says Devas. "And this food at Plenty tastes absolutely exceptional."

> "The beauty of truly vertical architecture is that the air can circulate freely"

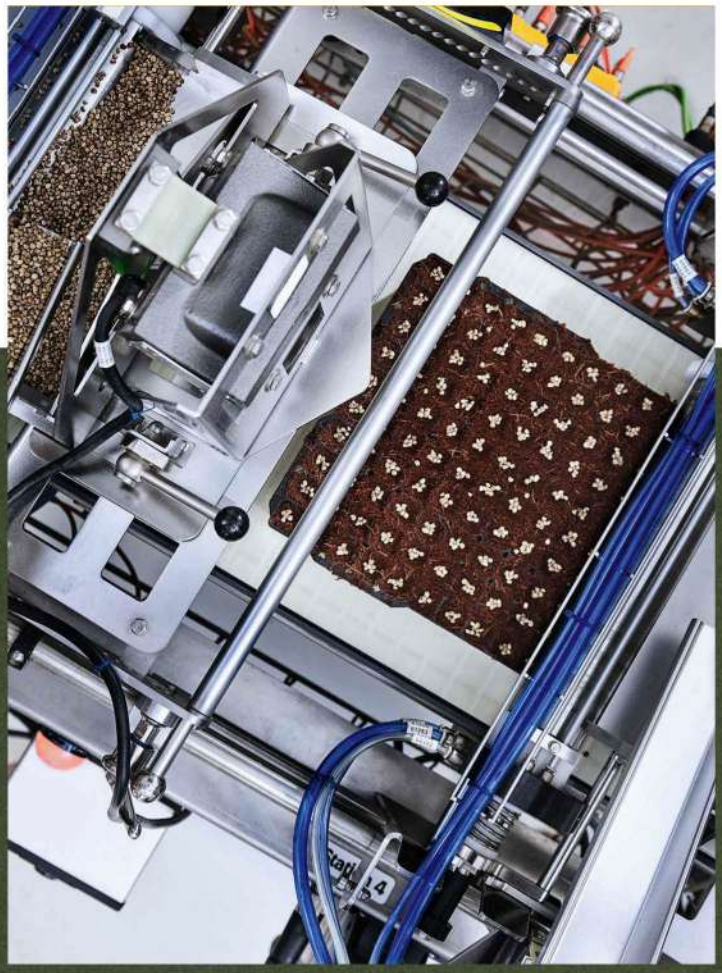
GROWTH STRATEGIES

Plenty's staff includes nearly 80 plant scientists. It's their job to decipher the optimal growing conditions for each plant and feed that information back to the company's more than 100 hardware and software engineers.

"Plants are really just little software programs," says Storey. "The DNA of a plant tells it what to do… what to build, how to react to the environment around it." By building a deep understanding of each plant's physiology, Plenty's scientists have learned how to push the buttons of the plants' DNA – without modifying it – to program qualities like growth, flavour, texture and nutrition. For →

CLOCKWISE FROM ABOVE Vertical towers crammed into a warehouse make for a more efficient use of space than horizontal rows spread across fields; LEDs shine specific wavelengths of light at the plants to boost growth and flavour; Plant plugs are transplanted automatically

PLENTY UNLIMITED X3



→ instance, hitting a plant with light at the bluer end of the visible spectrum, at the right point in its growth cycle, gives its leaves a satisfying crunch come harvest time.

Plenty has invested heavily in proprietary LED lighting systems that deliver what Storey calls, "the best parts of the Sun". Plants thrive on sunlight, but they don't use the entire spectrum to grow and develop flavour. Using a targeted spectrum of light, Plenty provides every wavelength the plants require, while also reducing the lights' energy demand and a little of the heat that they generate.

Traditional agriculture consumes 70 per cent of the planet's freshwater each year. On the Compton farm, the water supply is controlled on a plant-by-plant basis, and the vapour that evaporates from their leaves is condensed and put back into the irrigation system. The approach means that the farm uses less than a tenth as much water as field-based farms. It's a major boon in Compton's drought-stricken home state of California, where the main source of water (the Colorado River) is rapidly running dry. Meanwhile, the sealed environment means the Plenty crop can be grown completely pesticide-free. That means no washing, on the farm or at home, and no agricultural runoff.

A STEP IN THE RIGHT DIRECTION

The electricity needed to power and cool farms like the one at Compton mean that, for now, they're not a silver bullet to the climate crisis. But the grid is greening at a faster rate than anyone predicted, says Storey. Meanwhile, the environmental cost of conventional farming is only rising.

Climate instability is already having a disruptive impact on food supply. In the US, extreme weather events such as floods, storms, droughts and wildfires destroyed more than $21 billion worth of crops in 2022, making it the third costliest year on record.

But indoor farms are protected from extreme weather, which means they could have an immediate role in climate resilience and food security. Of course, the world can't live on lettuce alone. And staples such as wheat, and protein crops like soybeans are still a long way off being economically viable in the indoor setup.

ABOVE LEFT Crop towers work their way down towards the robotic arm in the harvesting room, which will unhook them from the ceiling

ABOVE Machines plant seeds into trays filled with a growing medium made of ground-up coconut husks

PLENTY UNLIMITED X2

Nevertheless, as companies like Plenty expand their range of crops, land that was once farmland can be returned to nature, giving it a chance to bounce back. "I view what we're doing as providing an alternative… to tilling up more soil, to cutting down more trees," says Storey. "If we can take pressure off marginal agricultural lands, and turn those back into wild spaces, that's the ultimate contribution to biodiversity."

Devas is also cautiously optimistic about vertical farming. A committed vegan who has witnessed, up close, the Amazon rainforest being cleared to make room for cattle grazing, he sees its potential for breaking the link between the growing need for agricultural land and species loss. In the 'Making Of' reel that accompanies *Planet Earth III*'s 'Humans' episode, his impression of Plenty's Compton farm is caught on camera: "It does feel like a really good start." SF

by CERI PERKINS
Ceri is a New York City-based science writer who specialises in the environment and nature. She holds a Bachelor's in Atmospheric Science.

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A BLUEPRINT FOR ANTI-AGEING

SCIENCE SAYS IT'S TIME TO RETHINK – AND TAKE CONTROL OF – OUR BODY'S AGE. HERE'S HOW TO SLOW, HALT AND POTENTIALLY TURN BACK YOUR BIOLOGICAL CLOCK

WORDS: ANDREW STEELE **ILLUSTRATIONS:** OLLIE HIRST

B

eing asked 'how old are you?' used to be a simple question to answer. If you weren't sure, you could always just count the candles on your birthday cake. The candles may no longer tell you the whole story, however. That's according to a growing group of scientists who claim that you don't just have a traditional chronological age, but also a potentially more fluid 'biological age'. And that biological age could even be wound back… if you know how.

The excitement about this idea began around 2013, with the first DNA tests that could estimate your age to within a few years. The fact that a person's DNA and chronological ages were usually slightly different raised a question: if the test deemed that you were older than your age in years, was that an error, or could it indicate something about how fast you're ageing on a biological level?

A decade of intervening research has shown us that people with an older DNA age, known more correctly as an 'epigenetic age', do indeed seem to be older biologically, and so they tend to get ill and die sooner than others. It's a scientific discovery that demonstrates what many of us have believed all along: people age at different rates. But what does this actually mean, both biologically and practically speaking?

Biologically, we now understand many of the underlying cellular and molecular processes that drive ageing, from damage to the proteins that keep our bodies working, to the ageing of cells themselves. It's these changes – known collectively as the 'hallmarks' of ageing – that are behind wrinkles, grey hair, frailty, memory loss and diseases like cancer, heart disease and dementia, all of which become radically more likely as we get older.

Practically, therefore, if we could slow these hallmarks down – whether through healthy lifestyle choices or, hopefully soon, medical treatments for the ageing process – we could reduce the risk of many or even all of the problems of old age at the same time.

For now, you might want to start by measuring your biological age to find out what you're working with. Don't rely on an epigenetic age test – although available from a number of providers, they're not cheap and results are too inconsistent. Instead, there are quite a few completely free measurements to try in the comfort of your own home to get a rough idea.

The first is just to gaze in the mirror and check how old you look. One study of Danish twins found those rated as looking older than their chronological age were at greater risk of getting ill or dying than participants who appeared more youthful.

There are physical measurements that can be tested too. Seeing how fast you can walk 10m (32ft) provides a gauge (with speed dropping from 1.4m/second – or 4.6ft/second – in those below 50 to less than 1m/second or 3.2ft/second in the over-80s); or you can try standing on one leg (under-40s can typically manage 45 seconds with their eyes open or 15 with their eyes closed, but that drops to 32 and 4 seconds respectively in 60–69 year olds).

"SOMEWHERE BETWEEN 75 AND 95 PER CENT OF LIFESPAN IS DOWN TO LIFESTYLE AND LUCK"

If these tests ring any alarm bells for you, there's some good news: science tells us that our rate of ageing isn't simply determined by genes. Studies ranging from comparisons of lifespan in identical twins, to massive number-crunching exercises on gigantic databases of family trees suggest somewhere between 75 and 95 per cent of lifespan is down to lifestyle and luck, a huge chunk of which we can control.

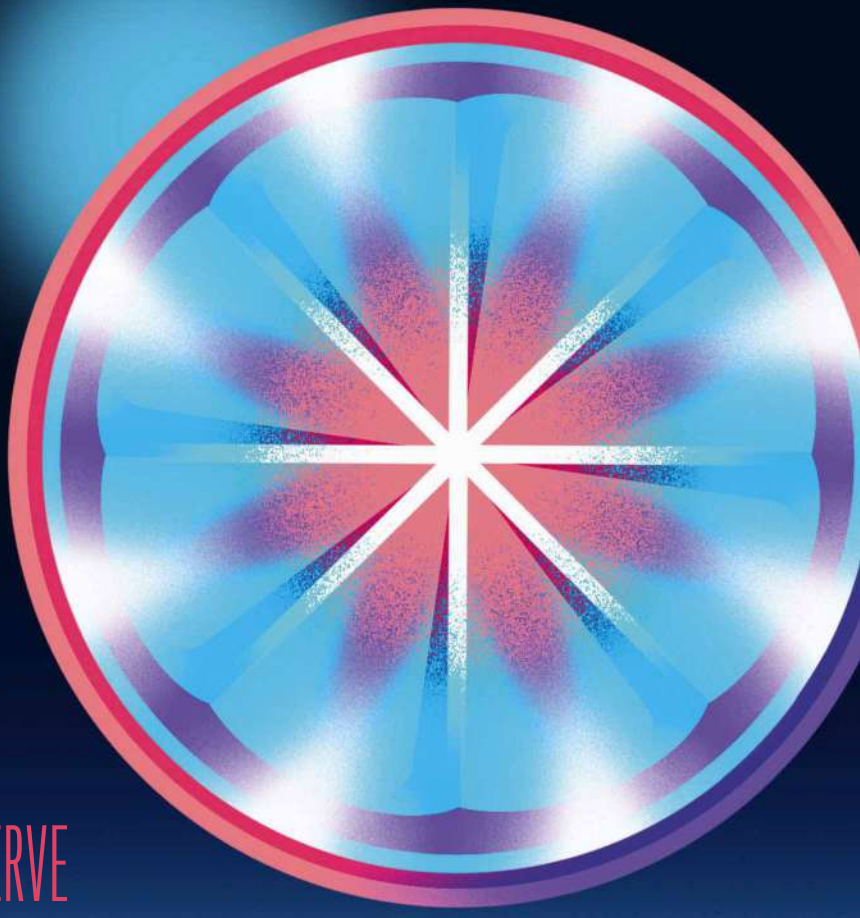
So, where should you start on your journey to delay – and possibly reverse – age-related decline? Science furnishes us with a range of suggestions, from the obvious to the obscure. →

MAINTAIN YOUR MUSCLES

Doctors joke that if exercise were a drug everyone would be queuing up to take it. Alas, getting fit is harder than simply popping a pill and many of us don't get enough of this miracle treatment – even though it seems to be able to slow the ageing process.

Most of us know that we should be getting 150 minutes of moderate activity (such as brisk walking), or 75 minutes of vigorous exercise, per week. What's often overlooked is strength training. Resistance exercise can help preserve both bone density and muscle mass, which are really important as we age, for a variety of reasons. Muscle even helps to regulate your blood sugar levels after meals, which our bodies often get worse at as we age.

We lose roughly 5 per cent of our muscle and 10 per cent of our strength every decade after the age of 30. But resistance exercise can delay or even reverse this decline. This doesn't need to be pumping iron at the gym: plenty of exercises can be done at home using your bodyweight, from press-ups to squats. It's never too late to start, either. One particularly inspiring study gave 90-somethings a two-month resistance training programme and nearly doubled their muscle strength in the process.

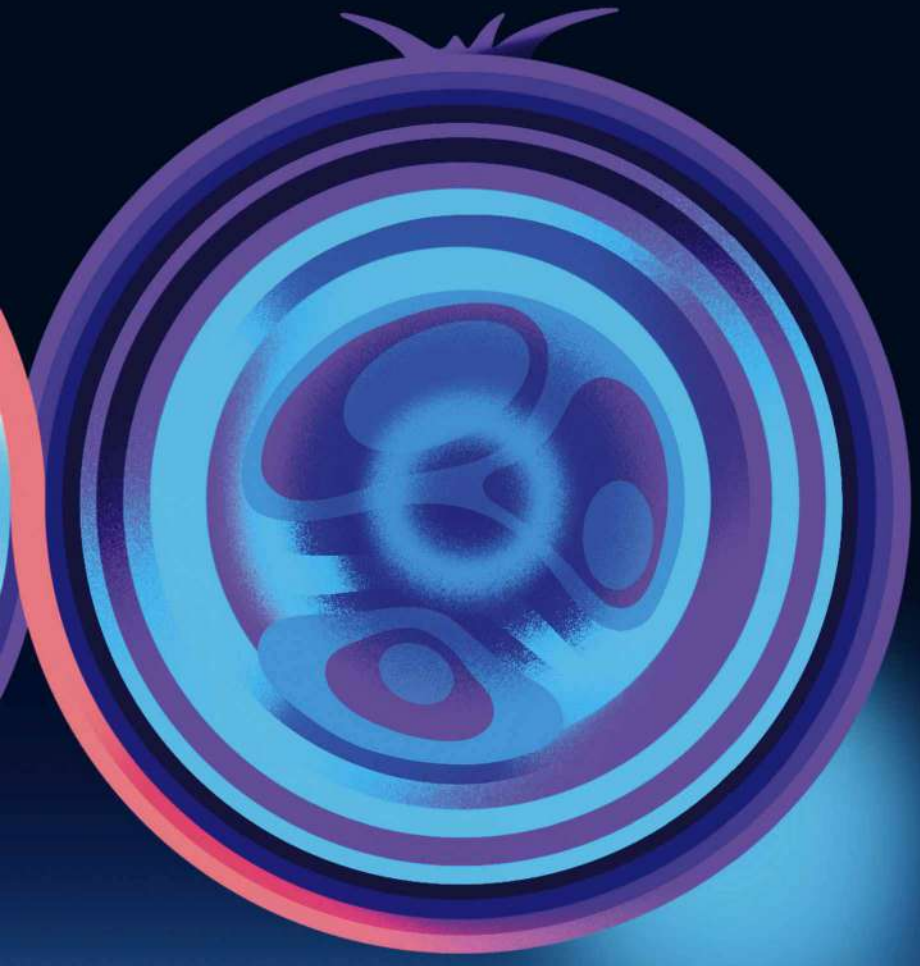


"RESISTANCE EXERCISE CAN HELP PRESERVE BOTH BONE DENSITY AND MUSCLE MASS"

IGNORE THE FAD DIETS

You could spend a lifespan just *trying* every diet put forward as the best way to increase health and longevity. Fortunately, the big picture is fairly straightforward: most of us would benefit from less meat and more vegetables, fruit, legumes, nuts and whole grains.

Exactly how much this could roll back your biological clock isn't clear, though. Diet studies are challenging, considering that the biggest ones are 'observational' – you can't enforce a diet on thousands of people over decades, so scientists make do with watching what people eat and observing what happens to their health.



BRUSH YOUR TEETH

One of the most surprising connections in ageing biology is that between good oral hygiene and living longer. The first hints of this came with studies noting that people with less tooth decay and gum disease seemed to have fewer heart attacks than those with worse oral health.

The exact link was unclear – there could have been an unrelated factor behind this correlation, or it might be that more health-conscious people spend more time brushing their teeth *and* engaging in other behaviours like eating well – but further studies have solidified the link. What's more, they suggested what the connection could be: chronic inflammation.

Inflammation, a normal immune response to an infection or injury, is usually short-lived. As we get older, however, our immune systems become a little paranoid, entering a state of constant low alert – inflammation that's chronic – and scientists think this can accelerate the ageing process.

A neverending battle with bacteria on your teeth or gums provides a source of exactly this kind of low-grade and long-lasting inflammation, providing a mechanism by which the cleanliness of your teeth is connected to general health.

The aforementioned recommendations do have the backing of shorter-term studies that closely prescribe a diet to participants and then use the likes of blood tests to monitor their key health markers. But what about when to eat? And how much? While there's solid evidence that maintaining a healthy weight is important for longevity, it's far less clear whether practices like fasting or long-term calorie restriction will be of benefit.

Calorie restriction works well in many organisms, like single-celled yeast, worms, flies and mice, but results in monkeys (the closest animals to humans we've yet tried it in) are more ambiguous. The evidence is thinner when it comes to fasting. Some human studies suggest it may result in weight loss, but disproportionately by loss of muscle rather than fat, which, given the importance of muscle at older ages, may well be a net negative for your biological age.

GET ENOUGH SLEEP, BUT NOT TOO MUCH

You've heard it before: studies suggest that the sweet spot for sleep is around 7-8 hours per night on average. But what you may not have heard as much is that having too much sleep can have a detrimental effect on your health. Regularly getting over nine hours of shuteye a night is associated with a higher risk of death than getting as little as four hours.

There are a variety of possible causes here: it could be that people who are unwell in other ways are more tired and so sleep for longer. Or it may be down to more complex biology, like more time in bed changing immune system behaviour for the worse. Currently, scientists aren't sure.

Though sleep remains one of the most mysterious aspects of our physiology, longevity science is uncovering mechanisms to explain how a good slumber can lengthen your lifespan. For example, while we sleep, our brains do a spring-clean, literally flushing out toxins, like the amyloid deposits associated with Alzheimer's disease, via a recently discovered network of pipes in our skulls, known as the glymphatic system.

Given that the accumulation of toxic proteins is one of the hallmarks of ageing, this could slow down brain ageing – hopefully making the well-worn advice to get enough shut-eye a bit more compelling.

"PEOPLE WHO GOT FEWER BUGS AS KIDS HAVE BEEN SHOWN TO AGE BETTER AS ADULTS"

ALWAYS WEAR SUNSCREEN

For all the potions making promises in the beauty aisle, by far the most effective anti-ageing cream is the humble sunscreen. As well as causing skin cancer, ultraviolet (UV) light emitted by the Sun accelerates the ageing of skin through a few different mechanisms.

Firstly, it damages the collagen and other structural proteins that make our skin strong yet supple in youth, leading to wrinkles and the skin being slower to return to position when pinched. (Incidentally, that's another at-home test of biological age.)

Secondly, the damage to our DNA caused by UV light means that almost all our skin cells are mutated by the time we reach our 50s. We don't yet know exactly how this contributes to ageing, but these mutations aren't present in young skin. Slapping on some sunscreen will help you maintain a more youthful mutational profile.

You need to seek out creams with factor 15 or higher and four or five stars for UV-A protection. It's worth applying sunscreen every morning since UV rays can be strong enough to damage skin on overcast days or through a window. With this regime, it's probably also worth supplementing vitamin D (10 micrograms a day), which is normally produced when UV light hits our skin.

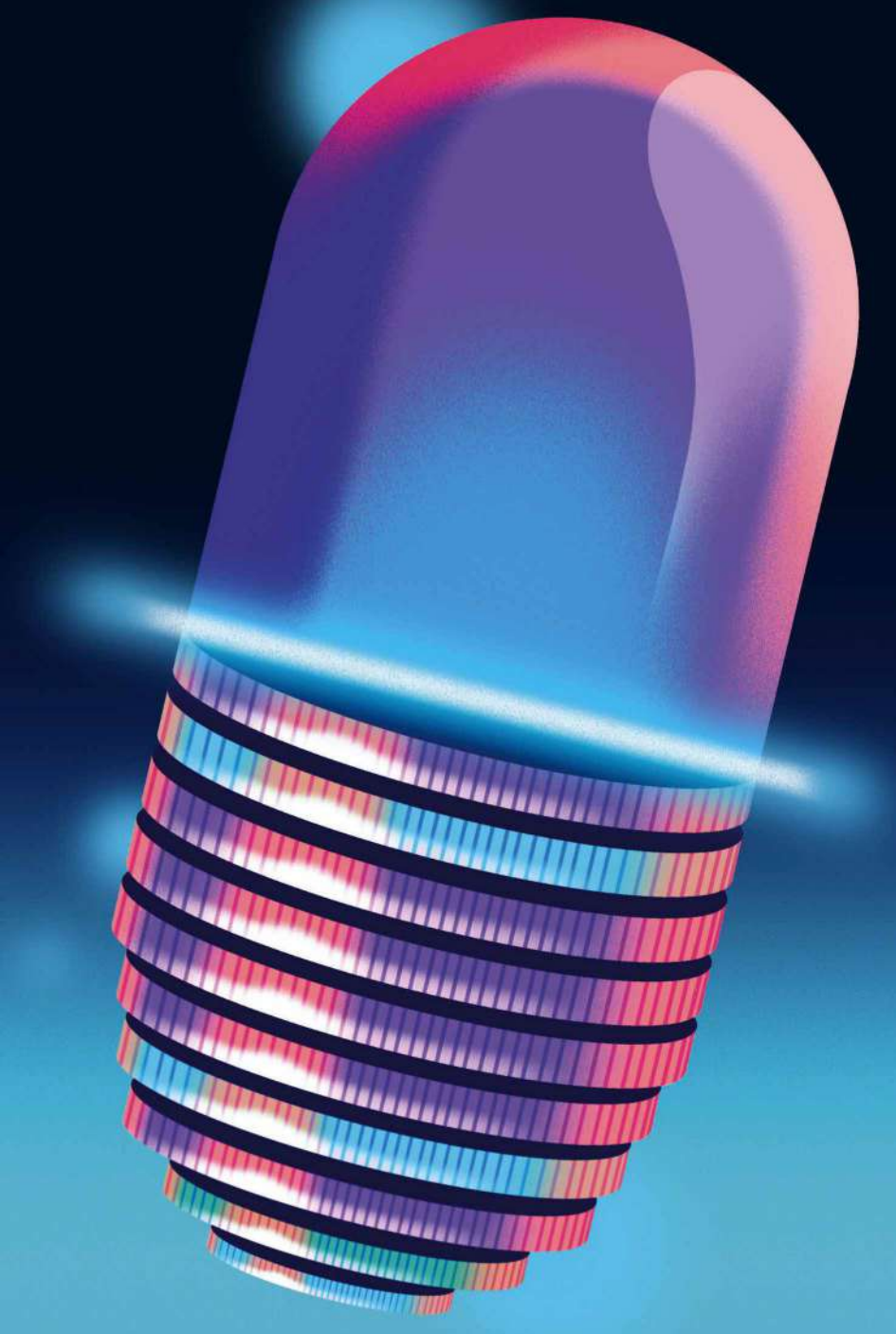
WEAR SUNGLASSES ALL YEAR ROUND

It's not only your skin that you need to keep safe from the Sun: looking after your eyes is just as important – and the effects of shielding them could include preventing dementia. That's because the damage that can be done by ultraviolet light has consequences that stretch beyond vision loss.

For example, the proteins in the lenses of your eyes are normally transparent, but UV damage may cause clouding and yellowing, which, if it gets severe enough, is known as a cataract.

UV light can also do damage to the light-sensitive cells on the back of the eye, accelerating the disease, age-related macular degeneration (AMD), which can blur your vision. Both cataracts and AMD seem to increase the risk of dementia. One theory to explain this is that by cloudiness or blurriness reducing the amount of visual stimulation received by the brain, cognitive decline with ageing accelerates, so protecting your eyes from UV light can slow down these processes and, in turn, could well reduce dementia risk.

The good news for those of you who wear glasses or contact lenses is that the majority of these come with built-in UV protection. For the rest of us, sunglasses – especially those that wrap around to prevent UV light from sneaking in at the sides – and a wide-brimmed hat are worth considering. These will not only help to maintain sight as you go into older age, but also brain function too.



PREPARE FOR FUTURE SUPER DRUGS

Perhaps the most important health tip for all of us in the medium term is to learn a bit more about the biology of ageing. That's because there are drugs on the horizon that could slow down the ageing process and keep more of us healthier for longer. Some could be drugs already available today, like metformin (a diabetes drug) or rapamycin (given to help transplant patients), which seem to have a broad anti-ageing effect.

Other new treatments could target one or more of the hallmarks of ageing, such as so-called 'senolytic' drugs designed to remove certain misbehaving cells, known as 'senescent' cells, that accumulate in our bodies as we get older. The science of longevity offers the promise of treatments far more powerful than the lifestyle tips currently at our disposal.

That's just another reason to stay as healthy as possible with the tools of today: in order to still be around to be able to benefit from the game-changing therapies of tomorrow.

DON'T WASTE YOUR SAVINGS

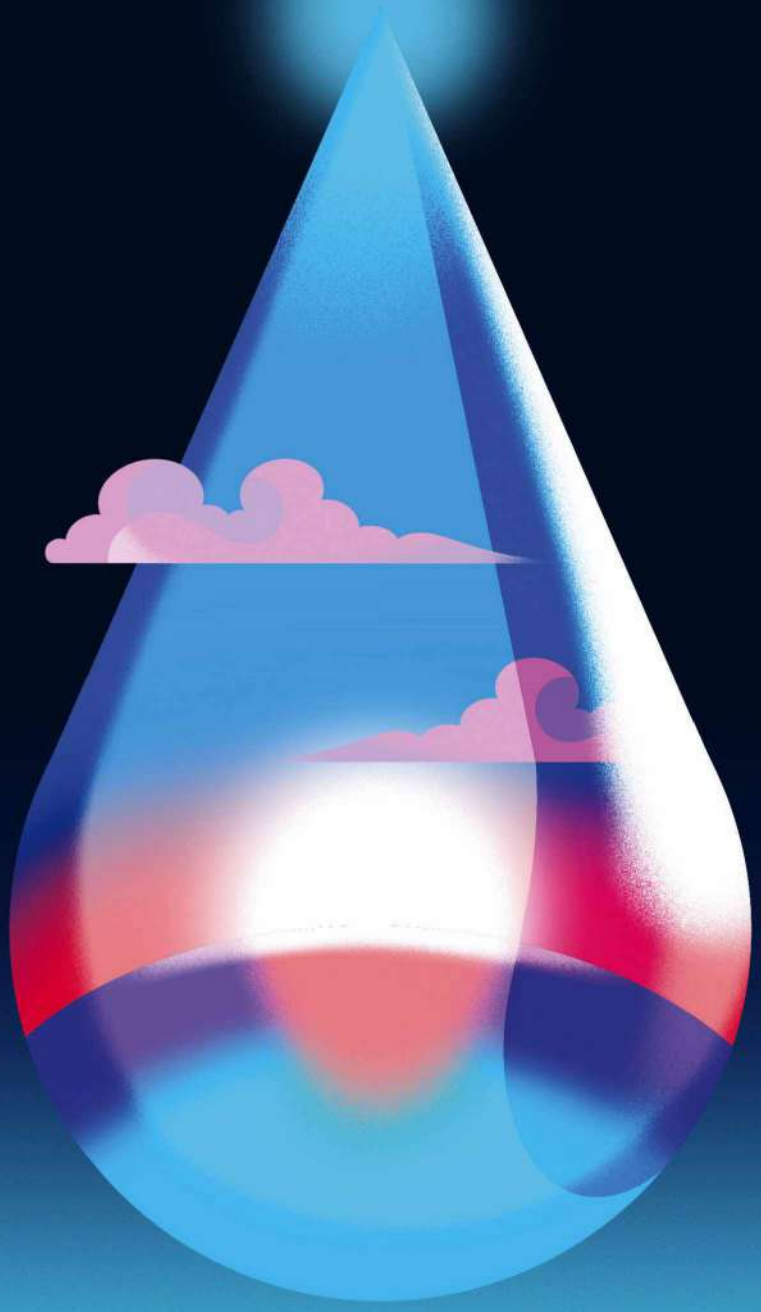
Perhaps the most talked-about story in ageing biology of late has been the tale of American entrepreneur Bryan Johnson, who is burning $2 million (£1.6m) of his reported $400m (£326m) fortune every year on dozens of tests, hundreds of daily pills and supplements, and an extreme diet, exercise and sleep regime in the hope of stopping his biological ageing.

For the rest of us, the good news is that there's no need to spend anywhere near that much. Almost all the bang for that considerable buck is probably coming from eating more vegetables, nuts and legumes; getting plenty of exercise; and consistent sleep patterns.

By contrast, scientific studies show that many common supplements have no effect on life expectancy, or sometimes a slightly negative one. If you're taking over 100 different pills, it's likely to reduce life expectancy overall: while some anti-ageing interventions add together, other combinations don't play nicely.

Biology is complicated and changing dozens of things at once doesn't make for a safe, controlled experiment, whether or not you're ultra-wealthy.

"STUDIES SHOW THAT MANY COMMON SUPPLEMENTS HAVE NO EFFECT ON LIFE EXPECTANCY"



WASH YOUR HANDS

If you heard it once during the pandemic then you heard it 1,000 times: wash your hands for 20 seconds, and be sure to scrub between your fingers and under your nails. We were told it would save lives by reducing the risk of infection, but washing your hands can boost your life expectancy too.

How? Firstly, we know that certain infectious diseases have a direct link to non-infectious ones later in life – from human papillomavirus (HPV) being the leading cause of cervical cancer, to a virus called cytomegalovirus (CMV) that seems to accelerate the ageing of the immune system. After an initial infection that's usually comparable to a mild cold, CMV hides away in your cells for the rest of your life. Because it can never quite get shot of CMV, ever more of your immune system ends up specialising in fighting it, leaving less 'immune memory' for other threats as we age.

There's even more general evidence suggesting that infections lead to problems in later life. As hygiene, vaccines and antibiotics gradually reduced the burden of infectious disease in childhood, people who got fewer bugs as kids have been shown to age better as adults. This is probably due to the same chronic inflammatory mechanisms as keeping your teeth clean.

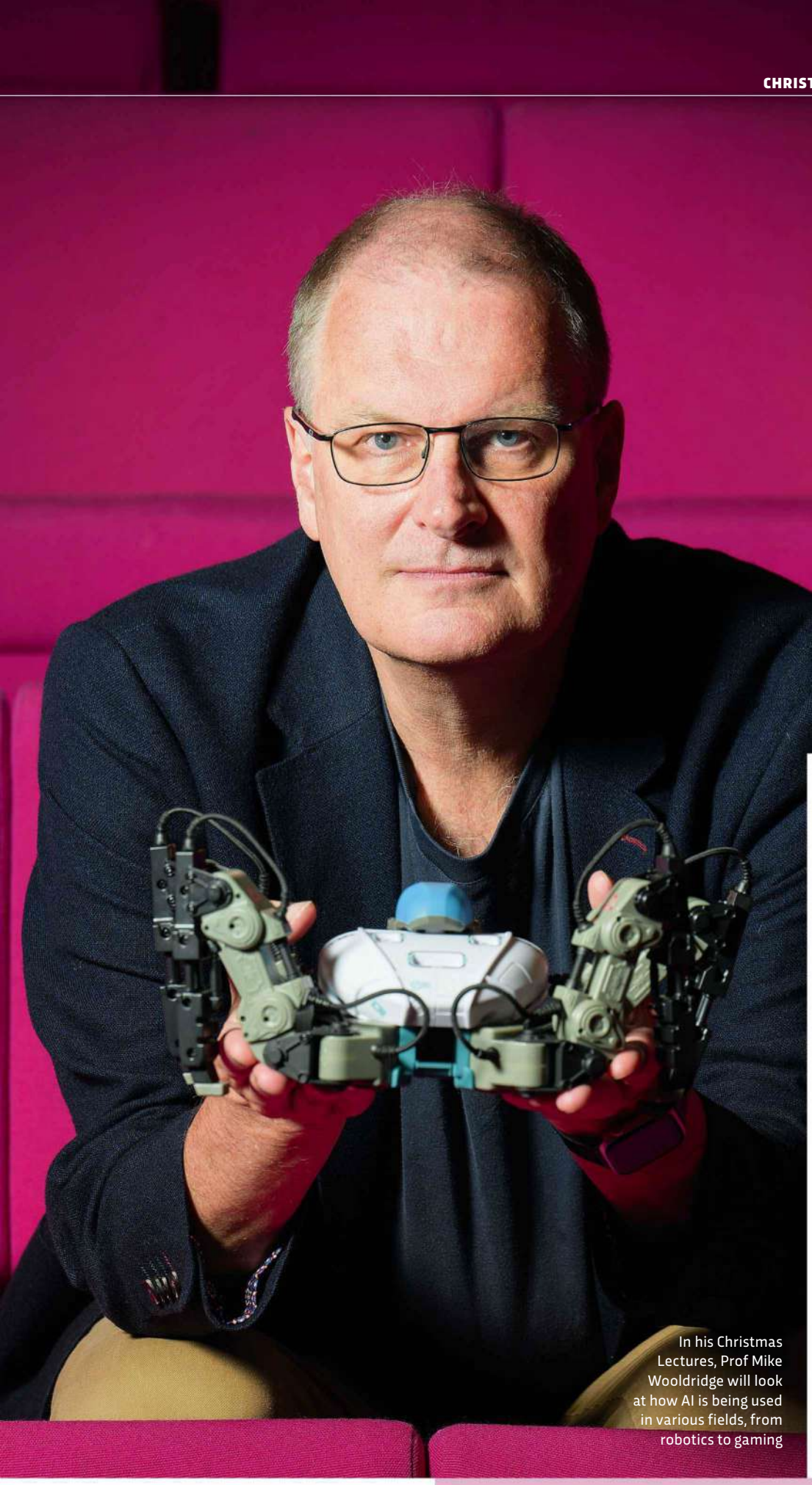
It means that doing everything you can to avoid infections might have a positive impact beyond the short-term desire to avoid the misery of being ill. SF

by ANDREW STEELE (@STATTO)
Andrew Steele is a Berlin-based scientist, writer and presenter. He is the author of Ageless: The New Science of Getting Older Without Getting Old *(Bloomsbury, 2020).*

UNDER THE HOOD OF ARTIFICIAL INTELLIGENCE

As the busiest year in the history of artificial intelligence (AI) comes to a close, Prof Mike Wooldridge prepares to deliver the Royal Institution's first Christmas Lecture on the subject. Noa Leach sat down with him to get a preview of the demonstrations his talks will include and an insight into how he thinks AI is going to change the world for children

PAUL WILKINSON PHOTOGRAPHY



In his Christmas Lectures, Prof Mike Wooldridge will look at how AI is being used in various fields, from robotics to gaming

BBC FOUR

WATCH

See Prof Mike Wooldridge deliver this year's Royal Institute Christmas Lectures on BBC Four. Or stream them on BBC iPlayer.

In The Royal Institution's almost 200-year history of Christmas Lectures, the topics covered have swept through chemistry, mechanical engineering and astronomy to psychology, climate change and, this year, artificial intelligence (AI).

Many people are concerned about how AI is going to change our healthcare, careers and entertainment, but what do the experts think? Mike Wooldridge is a professor of computer science at the University of Oxford and has been selected to deliver this year's Royal Institute Christmas Lectures on AI.

What was your reaction to being selected to give this year's Royal Institution Christmas Lectures?

I was stunned. The Christmas Lectures were one of the treats over the Christmas period for me as a kid – I was really into science and I can remember watching them in the 1970s.

I remember watching the astrophysicist Carl Sagan talking →

→ about the planets and being absolutely entranced by his lectures. More recently we had Sir David Attenborough. David Attenborough!

Following in their footsteps is really quite something. For so many British scientists, the Christmas Lectures were one of the things that kindled their interest in science. To be part of that legacy is amazing.

The Christmas Lectures are famous for their props. What can we expect to see in your talk?

The first thing the RI team told me is that it's a tradition to have an explosion and a dog (ideally at different times). So there will be an explosion and there will be a dog, but I'm not saying any more than that.

What I will say, is you're going to see lots of demos on how AI works in computer games. A lot of children spend their leisure time gaming and they may not realise that there's a lot of AI behind the scenes in computer games. So we're hoping to get some kids out of the audience to play with some of the most sophisticated AI game technology in the world. Lucky kids!

We're also going to do a live Turing Test. Until the last couple of years, we didn't have computer programs that could realistically pass the Turing Test [and be able to converse in a manner that's indistinguishable from a human]. Then all of a sudden, we have programs that could plausibly pass it. As an AI researcher who's been working in this field for so long, to suddenly have that opportunity is enormously exciting. So we're going to see what happens – I don't know how it's going to come out.

The aim is to demystify all of this. So we'll also play some games that explain how ChatGPT works. We'll show people what's going on 'under the hoods' of these AI programs. I hope to really show that there's nothing to be afraid of with AI.

Some parents and teachers worry about children becoming endlessly diverted by AI entertainment, or over-relying on it for their homework. What would you say to them?

Fears about technology being a threat to civilisation are nothing new. I remember in the 1970s, when pocket calculators became widely available, people had exactly the same fears: they worried that kids wouldn't learn how to do arithmetic and that they would do all their homework on the calculator.

But mathematics didn't collapse. What pocket calculators did for us is they just relieved us of a very tedious burden. Pocket calculators enable many people to do the arithmetic that they don't particularly enjoy doing, and do it more quickly and more reliably.

My guess is that, in the long run, that's exactly what will happen with AI technology. It'll just be another tool, similar to pocket calculators.

Thinking along those lines, I hear lots of teachers are hoping that AI might soon be able to do their marking for them. Do you see that happening? How else could AI be used in the classroom?

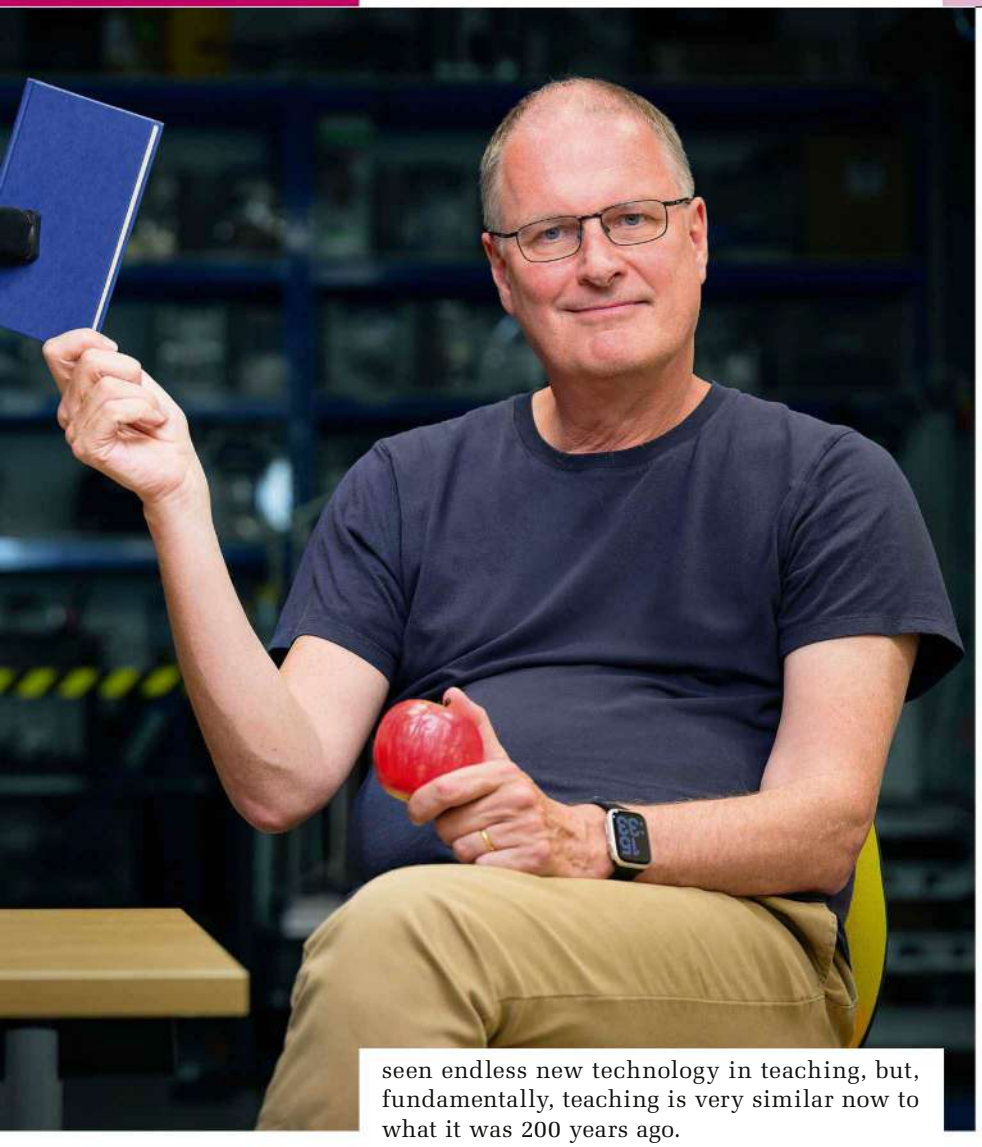
I'd be nervous about using it for marking right now, because AI gets things wrong a lot. I think it could [perform that task] ultimately, but human judgment is very important for marking.

But I think AI will have its place in the classroom. One of the unexpected benefits of tools like ChatGPT is that they're really good for brainstorming. It can prime a teacher on different subjects and give them ideas about how to present things in new and interesting ways.

The dream of AI in education is that we'd end up with AI tutors. That is, you end up with something like where ChatGPT takes the role of a teacher. I think teachers are safe in their jobs for the foreseeable future though. We've

PAUL WILKINSON PHOTOGRAPHY, ALAMY

I HOPE TO REALLY SHOW THAT THERE'S NOTHING TO BE AFRAID OF WITH AI



Prof Mike Wooldridge investigates how logic, computational complexity and game theory interacts in computational systems

seen endless new technology in teaching, but, fundamentally, teaching is very similar now to what it was 200 years ago.

Some studies are investigating what happens to a child's psychology if they're consistently rude to an AI in a way that they wouldn't be with a human. Should we encourage children to respect AI and see them as friends?

On the one hand, I think this technology is just a tool. Swearing at an Excel spreadsheet (which I do most days) is not intrinsically wrong – and neither is swearing at ChatGPT.

Where it becomes difficult is if the AI is presented with a human persona. Abusing an Excel spreadsheet doesn't feel wrong, but how would you feel about abusing a humanoid robot with something like a human head and eyes?

I think most of us would feel, at the very least, uncomfortable about that – because it somehow takes it a lot closer to abusing human beings. So I think one of the important principles about AI is that it should never be presented as if it's a human being – that it should always be presented as a tool.

I think the truth is, we just don't know yet. But I definitely think this is something that we need to keep an eye on. SF

A HISTORY OF AI IN FIVE CHRISTMAS LECTURES

2023 marks the first time AI has been the primary topic of the Christmas Lectures. But over the last two decades, five Royal Institute Christmas Lectures have heralded the technology's arrival in the public's mind...

2000

Despite Alan Turing predicting that a computer would pass his test by the turn of the century, when cybernetics professor Kevin Warwick (above) gave his lecture, which included a Turing Test, no AI had made the grade. It's still unclear whether the Turing Test has been passed, but Prof Mike Wooldridge hopes to challenge this in his lecture.

2008

In 2008's Christmas Lectures, Prof Chris Bishop explained the difficulties in building intelligent machines for visual processing. To demonstrate, Bishop used three volunteers to test a new technology that identifies individual penguins by their front markings.

2013

Biologist Prof Alison Woollard played with facial ageing software – as seen today in many social media image filters – in her Christmas Lectures to explain the biology of ageing.

2018

Prof Alice Roberts and Aoife McLysaght explored how emerging technologies might be able to use genetics to predict our risk of disease. Two years after their lecture, deep learning system AlphaFold made headlines with its success in predicting protein structures.

2022

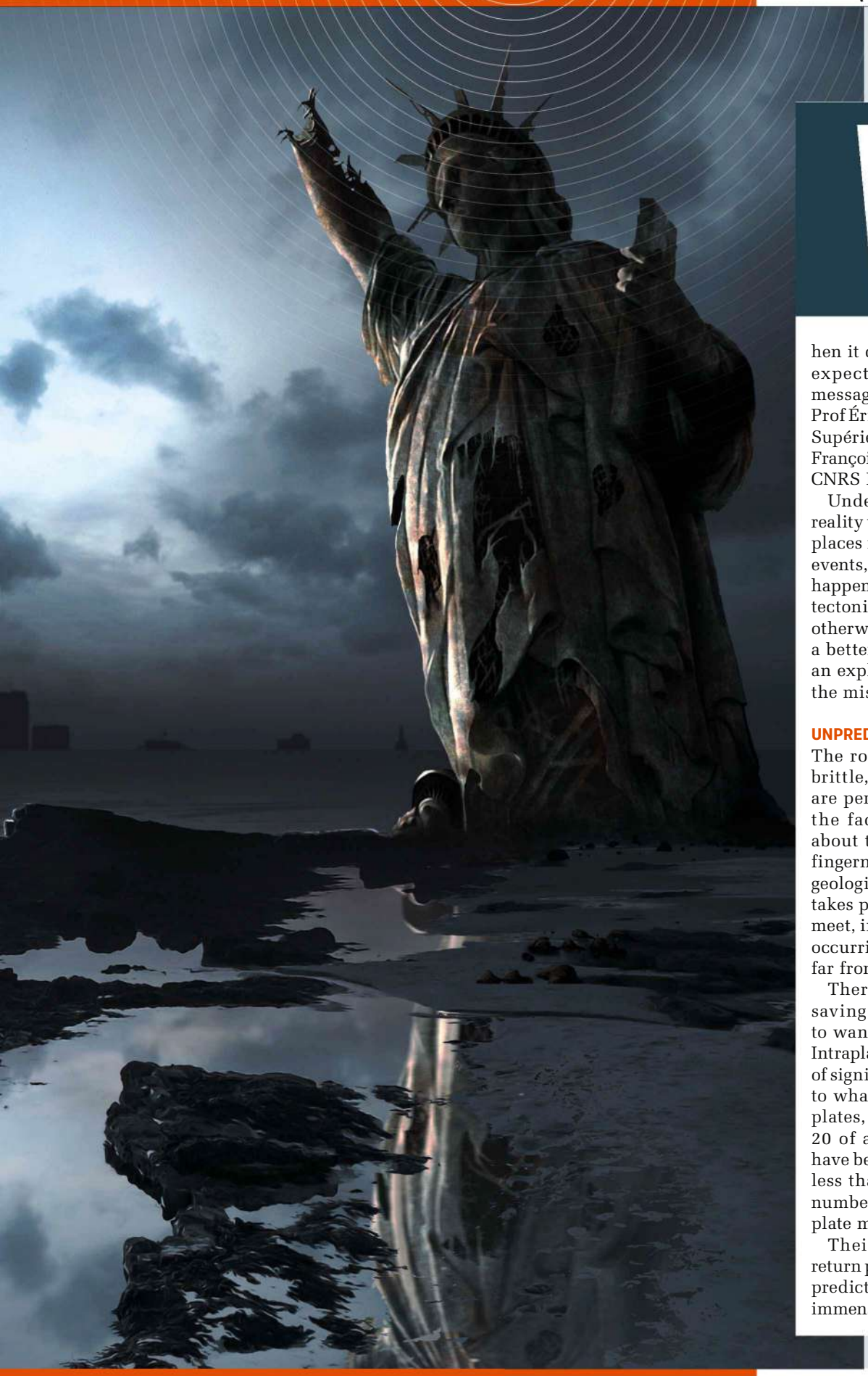
Prof Dame Sue Black's lectures on forensic science included a short courtroom drama, in which Black called up a computer scientist as a 'witness' to talk about using AI to extract anatomical information from images of a perpetrator's hands.

STRANGE RUMBLINGS

Earth-shattering seismic events can occur away from the fault lines between tectonic plates. And there's no easy way to predict when or where they'll hit

by PROF BILL McGUIRE

GETTY IMAGES



When it comes to earthquakes, always expect the unexpected. That's the message coming from seismologists Prof Éric Calais, of the École Normale Supérieure (ENS) in Paris, and Jean-François Ritz, Director of Montpellier's CNRS Laboratoire Géosciences.

Underpinning their advice is the reality that Earth sometimes shakes in places it shouldn't. These mysterious events, called intraplate earthquakes, happen far from the active margins of tectonic plates and in places that are otherwise geologically quiet. Gaining a better understanding of them and an explanation for them has become the mission of the French scientists.

UNPREDICTABLE AND DESTRUCTIVE

The rocky plates that make up the brittle, outer carapace of our world are performing a slow dance across the face of the planet, moving at about the same rate that a person's fingernails grow. While nearly all the geological action worth talking about takes place where the tectonic plates meet, intraplate quakes are different, occurring in the interiors of the plates far from the margins.

There are good, potentially life-saving, reasons for Calais and Ritz to want to shed more light on them. Intraplate quakes are rare: the number of significant shakes is tiny compared to what happens at the edges of the plates, with Calais noting that only 20 of a magnitude of 6 and above have been recorded since 1974. That's less than half of one per cent of the number of similarly sized quakes at plate margins over the same time.

Their rarity, and typically long return periods, makes them difficult to predict, yet they're capable of causing immense destruction in unprepared →

→ urban centres that never regarded quakes as a problem.

Intraplate earthquakes can happen anywhere that a geological fault is present in the crust. In the last few centuries, they've been recorded as far apart as Basel in Switzerland, New York and Boston in the US, and the St Lawrence River in Canada.

More recently, they've caused substantial damage in the Australian city of Newcastle and, in 2017, in the southern African country of Botswana and Puebla, Mexico, the latter resulting in close to 400 deaths.

THE MAGNITUDE OF THE PROBLEM

Calais and Ritz draw attention to a magnitude 5 earthquake that happened close to the Rhône Valley village of Le Teil in 2019, while in 2008 a magnitude 5.2 event beneath the Lincolnshire town of Market Rasen rocked much of England. What a local newspaper referred to as "The Great Rasen Earthquake" injured one person and caused damage estimated at around £20 million.

While the tremors that strike the UK and France tend to be small, this is far from the case in other parts of the world. In 2001, the most devastating intraplate quake of modern times – a magnitude 7.6 event that struck Bhuj in the Indian state of Gujarat – destroyed an estimated 300,000 buildings and claimed up to 20,000 lives.

Going further back in time, a quake of magnitude 7 (or thereabouts) hit the US east-coast city of Charleston in 1886, killing 60 people and inflicting

"MINING AND THE FILLING OF NEW RESERVOIRS HAVE BEEN LINKED TO INTRAPLATE SEISMICITY"

widespread damage. A little over 80 years earlier and around **1,200km (approx 765 miles) to the west, thre**e powerful **intraplate quakes struck in the New Madri**d region of **Missouri from December 1811 to February 181**2.

Registering magnitudes of up to 7.5, these resulted in **violent tremors across an area almost three ti**mes the size **of those that hit the UK and 10 times larger** than those **associated with the great San Francisco ear**thquake of **1906. As the region at the time was sparsely** populated, the overall impact was not as devastating as it could have been, but local destruction was severe.

In Europe, cities far from a plate boundary are at risk from large, if rare, quakes, including Brussels in Belgium, and Geneva and Basel in Switzerland. The latter is of particular interest: on 18 October 1356, a series of violent intraplate quakes – the largest being a magnitude of 6.6 – and the

SHUTTERSTOCK, USGS, GETTY IMAGES

fire that followed, destroyed huge areas of the city.

Despite being one of the largest recorded quakes in central Europe, the human toll was smaller than could be expected as the population of Basel was only about 6,000, and many had already fled when the main event happened due to a powerful foreshock earlier in the day.

ADDING TO THE STRAIN

One thing that both intraplate earthquakes and those at the plate margins have in common is their operating mechanism. Essentially, strain accumulates over time on a geological fault – a weakness in the Earth's crust – until it reaches a critical level that causes the fault to break or rupture. This is what causes a quake: the rupture releasing energy in the form of seismic waves so as to reduce the strain to zero. Then, the whole process starts over.

Strain can accumulate along the great geological faults that mark the contacts between individual plates, such as San Andreas in California. At the plate boundaries, this strain is monitored using GPS, strain meters and other methodologies, and – based on the average return period of past quakes on a fault – rough estimates can be made about when the next is likely to happen.

Calais observes that the frequency in California is typically a couple of hundred years. In relation to faults that host intraplate quakes, however, there's a problem. Such structures are often old and deeply buried, and on occasion their existence isn't suspected at all until after they've hosted an earthquake.

The absence of any record of past events makes it impossible to estimate when the next one might happen. Indeed, as Calais points out, some intraplate quakes might even be so-called 'orphan' events that aren't part of a series and which involve the one-off reactivation of an ancient fault that hasn't ruptured for millions of years.

While the mechanism of strain accumulation and release is the same for both intraplate quakes and those that happen at plate boundaries, the triggers that cause rupture may well be different. Fault rupture at the edges is provoked by plate movement, but Calais and Ritz propose something different for the plate interiors: discrete triggers that occur rapidly, at least on a geological timescale.

These can include unloading due to the melting of ice sheets or surface erosion; rainfall seeping down from the surface; or fluids working their way up from the Earth's mantle. Mining and the filling of new reservoirs have been linked to intraplate seismicity, as well as, extraordinarily, the atmospheric pressure fall that arises from the passage of a tropical cyclone.

INTRICACIES OF THE INTRAPLATE

At this point, it's worth noting that a fault that's primed and ready to rupture can be induced to do so by pressure equivalent to that of a handshake. So, while it may have taken millions of years for strain to accumulate on an ancient intraplate fault, setting it off can happen over a relatively short period of time.

Calais and Ritz have zeroed-in on the aforementioned 2019 Le Teil quake and come to the conclusion that it was probably triggered by an unloading of the crust above following the melting of glaciers in the region at the end →

ABOVE LEFT An aerial view of damage caused in Mexico City by the 2017 Puebla earthquake

ABOVE RIGHT An intraplate earthquake struck the US city of Charleston in 1886, killing 60

FAR LEFT Jean-François Ritz has been investigating intraplate quakes in Le Teil, France

→ of the ice age, perhaps aided and abetted by nearby quarrying.

In fact, unloading and deformation of the crust due to the rapid melting of the great ice sheets between about 20,000 and 10,000 years ago has been implicated in the promotion of many intraplate quakes, including New Madrid, Charleston and Basel.

At the end of the ice age, Norway and Sweden experienced an earthquake 'storm' as a result of the rapid melting of the 3km-thick (1.9-mile) Scandinavian Ice Sheet, which unloaded intraplate faults beneath and allowed them to release the strain that had been accumulating over tens of thousands of years. The result was a number of colossal magnitude 8 quakes, one of which – around 8,200 years ago – triggered a giant submarine landslide off the coast of Norway that launched a tsunami into the North Atlantic. The waves reached heights of 20m (65ft) across Shetland and 6m (20ft) on the east coast of Scotland.

ABOVE The Russell Glacier in Greenland is melting at an alarming rate, having a potentially dramatic effect on the tectonic plate beneath

BELOW Intraplate earthquakes are rare, with most geological activity taking place at the edges of the plates

PREDICTION WOES

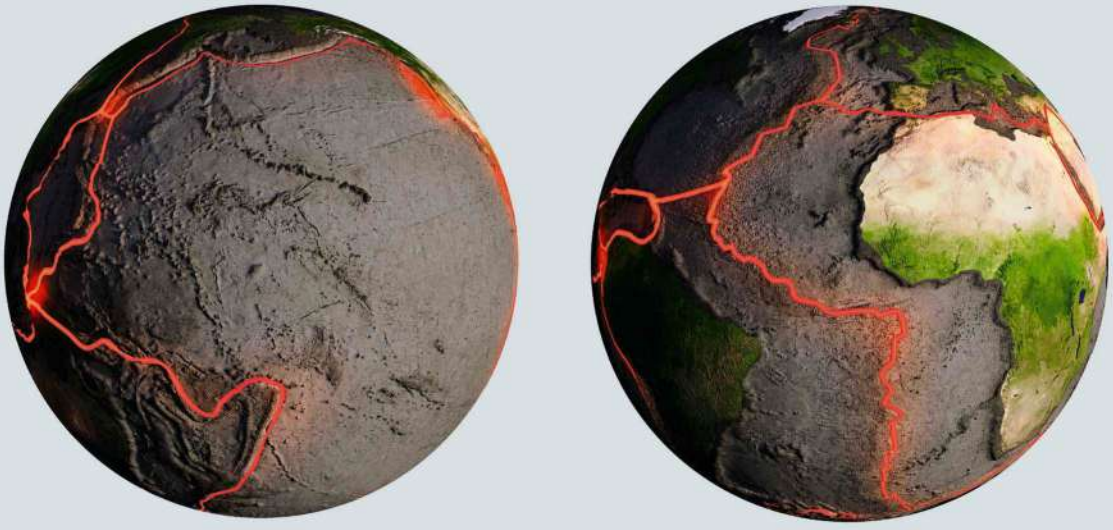
So what does this all mean for the future? Calais highlights the difficulty of predicting intraplate quakes. "With these special earthquakes, it's very complicated to calculate future risks, especially as they can sometimes only occur once in a given location," he says. "We lack objective indicators to assess future intraplate seismicity."

Nonetheless, studies have been undertaken that focus on the threat posed by intraplate quakes in areas that have been affected by them in the past. The results make for unnerving reading.

Today, more than half the world's population is urbanised, and cities in areas affected by intraplate quakes have grown considerably in size. Basel, for example, is now the second largest urban centre in Switzerland, hosting a population of around half a million people, and the city is a major centre for banking and the chemical industry. The consequences of a quake similar to that of 1356 would be far more serious. According to the Swiss Seismological Service, this would result in 3,000 deaths and up to 80,000 buildings suffering moderate to very severe damage.

In the US, Charleston is now an urban centre of more than three quarters of a million people, mostly living in

"AT THE END OF THE ICE AGE, NORWAY AND SWEDEN EXPERIENCED AN EARTHQUAKE 'STORM'"



ABOVE The aftermath of a massive intraplate earthquake near Bhuj, India, in 2001, as the country prepared for its annual Republic Day. With a magnitude of 7.7, it obliterated infrastructure and caused around 20,000 deaths

masonry or concrete buildings, rather than wooden as at the time of the 1886 earthquake. That means any comparable event would be both far more destructive and deadly.

Even worse, a 2009 study funded by the US Federal Emergency Management Agency (FEMA) predicted that, were there to be a magnitude 7.7 quake in the vicinity of the early 19th century events in New Madrid, the impact would be felt across eight states, with Missouri and Tennessee the hardest hit. The major urban centres of Memphis and St Louis would be the most severely affected, leading – the study estimated – to more than 700,000 damaged buildings, 3,500 deaths and the displacement of more than 7 million people.

New York is far from safe from a future quake, too. Although a magnitude of 7 is possible, having an estimated return period of 3,400 years means that an intraplate quake is extremely rare. Consequently, there's no requirement for buildings to be able to stand up to the shaking arising from a quake of that size. The corollary is that, if one happened, hundreds of thousands of buildings would be destroyed or damaged, and thousands of people killed.

But much smaller events could also significantly impact a city that's poorly prepared. Even a magnitude 5 quake, comparable to one that struck New York in 1884 and expected every hundred years or so, could be lethal and result in a repair bill adding up to billions of dollars.

When it comes to future intraplate earthquakes, there's one other major factor to consider: global heating. As glaciers and ice sheets melt, the reduced load on the crust beneath is leading to faults releasing long-accumulated strain. This has been observed in parts of Alaska, where a vertical kilometre of ice (0.6 miles) has been lost in some areas.

The big worry, however, is Greenland. In 2019, the ice sheet shed more than half a trillion tonnes of ice, which is enough, when melted, to flood the whole of the UK to a depth of 2.5m (8ft). The crust beneath is uplifting as a consequence and an eventual hike in intraplate quake activity has been predicted.

While Greenland is sparsely populated, the potential for such quakes to trigger submarine landslides capable of generating tsunamis means that everyone living around the margins of the North Atlantic should take note. Could it be that we're facing a shakier future, as well as a much hotter one? **SF**

by **PROF BILL MCGUIRE** (@ProfBillMcGuire)
Bill is a volcanologist, and Emeritus Professor of Geophysical & Climate Hazards at University College London.

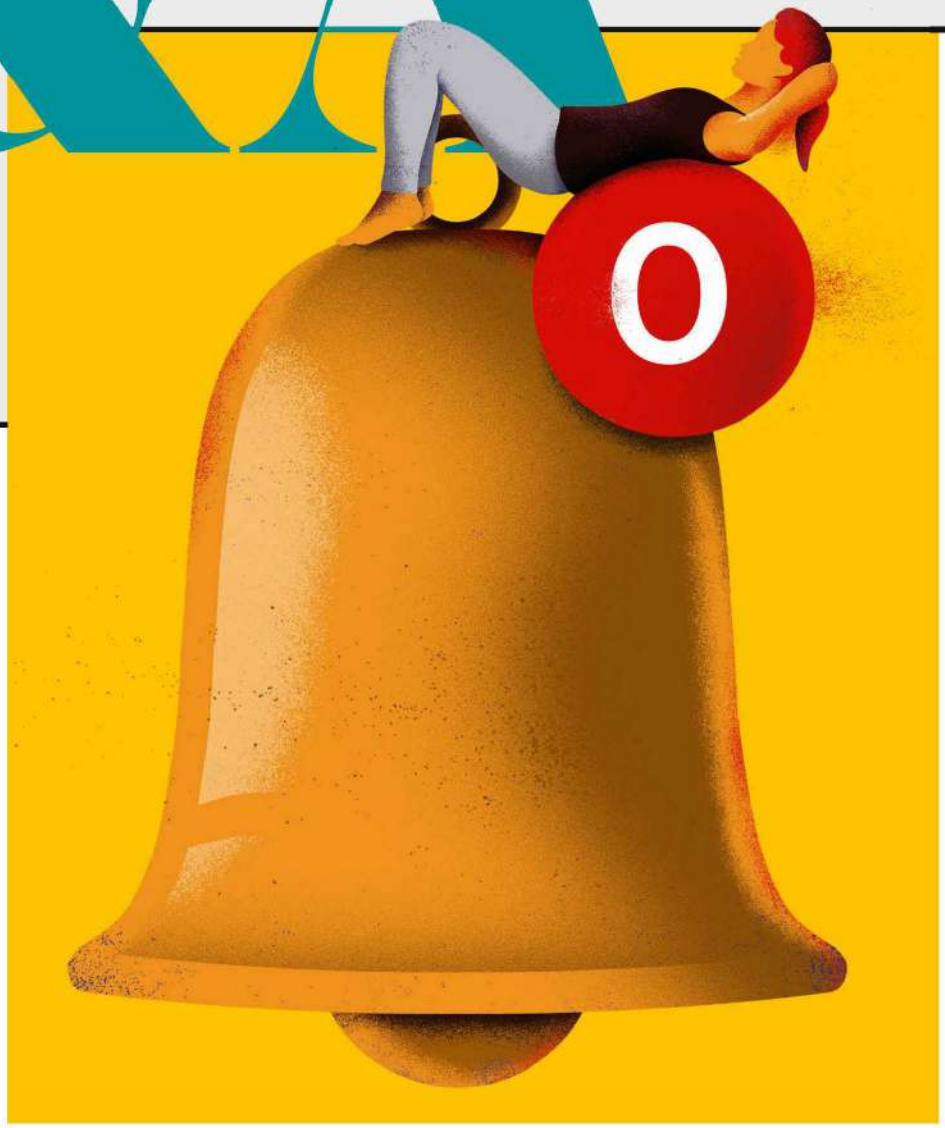
ALAMY, SHUTTERSTOCK, GETTY IMAGES

Q&A

LUIS VILLAZON
Engineering and technology

PROF STEVE BRUSATTE
Palaeontology

YOUR QUESTIONS ANSWERED



CARA SAUNDERS, VIA EMAIL

IS THERE ANY SCIENCE TO LOW-DOPAMINE MORNINGS?

If you frequent the 'how to be productive' part of TikTok, you've probably come across the latest 'hack' for staying focused and avoiding procrastination: starting your day with a low-dopamine routine.

According to the low-dopamine morning trend, the activities you do within the first 90 minutes of waking will determine what your brain craves for the rest of the day.

If, upon switching your alarm off, you immediately open Facebook or Instagram, then your first dose of dopamine is coming from your smartphone. So when you're at your desk later on and struggling to concentrate, you'll find it difficult to resist turning to your phone in search of another dopamine hit, warn the TikToks.

Instead, low-dopamine mornings are designed around tasks that are calming (or boring), rather than engaging. That way, your brain won't feel the deficit in dopamine when you begin work. For example, reading the morning news can be swapped with an easy household chore, while your high-intensity workout can be replaced by a slow walk, yoga routine or meditation.

Here comes the but: the science behind low-dopamine mornings isn't as straightforward as the trend suggests. Though it's often referred to as the 'reward chemical', dopamine is much more complicated. The neurotransmitter is involved in a whole host of processes in the body, including movement, attentional control, breast milk production, and forming associations between activities and feelings of pleasure.

These associations aren't just limited to happy experiences. Unpleasant ones can also trigger an increase in dopamine, which is thought to reinforce an aversion toward the activity. As such, a surge in morning dopamine in response to a harrowing news story could make you want to scroll less on your phone, not more.

Low-dopamine mornings often involve low-intensity exercise, such as walking or yoga. But these activities can increase dopamine levels in some, while the exercises that you're advised to avoid (running or weight training, for example) don't always lead to dopamine release. For regular

VALENTINA HERNANDEZ GOMEZ Yoga

DR ALASTAIR GUNN Astrophysics

DR EMMA DAVIES Food & chemistry

DR HELEN SCALES Marine biology

AMY ARTHUR Lifestyle & wellness

DR CHRISTIAN JARRETT Psychology

DR HELEN PILCHER Biology

CERI PERKINS Nature & environment

PROF PETER BENTLEY Technology

runners, spending 30 minutes on a treadmill was found to have no impact on the dopamine levels in their brains.

This isn't to say that you won't feel better if you spend your mornings not scrolling through social media or taking a walk outside. Spending time in nature has many cognitive benefits and light exercise is good for your heart, muscles and mind. But it's not an activity's impact on dopamine that makes it worth doing or avoiding.

To be more productive and reduce procrastination, it's worth thinking about your behaviours individually. If you're easily distracted by notifications on your phone or noise in the office, consider how you can set

"THOUGH OFTEN REFERRED TO AS THE 'REWARD CHEMICAL', DOPAMINE IS MUCH MORE COMPLICATED"

up barriers around your attention. Switch off your phone, or at least put it out of sight. Use earplugs or listen to something designed to be in the background, such as relaxing music, rainfall or coffee shop noises.

If you're concerned about your smartphone use, there is one element of the low-dopamine morning trend that you might benefit from: setting rules around when you use your device. Often, we mindlessly reach for our phones whenever we're bored, but making the mindless intentional can help us control habits, rather than feel ruled by them. If you decide on set times to use your phone, you can still get warm, happy feelings from watching cat videos on Instagram, but without the side helping of guilt. ***AA***

GETTY IMAGES X2 ILLUSTRATION: SEBASTIEN THIBAULT

RAYMOND WILSON, HIGH WYCOMBE

WHY DOES MELTED CHEESE TASTE SO GOOD?

Humans are hardwired to enjoy eating fat. The process of melting releases fat from cheese, where it has been held by networks of milk proteins. Heating causes the networks to relax, pushing out water and leaving gaps for fat to move through. Heat also brings out amino acids with a savory 'umami' taste, such as glutamate. If you overheat your cheese, however, you'll be left with clumps of protein and puddles of grease.

But it's not only the taste we enjoy; the smell's pretty special too. A recent study identified 50 volatile chemicals released from melted cheese, many of which derive from buttery fatty acids. ***ED***

NOEL GIBSON, BATH

WHY ARE THERE 12 NOTES IN AN OCTAVE?

It's a combination of biology, maths and physics. If you play a tone with a frequency of 440Hz then you get an A. Doubling the frequency to 880Hz changes the note to an A one octave above. Our ears hear this as essentially the same note, just pitched up. Within this range, certain ratios sound more pleasing than others; the most important being the 'perfect fifth' (3:2) and the 'major third' (5:4). Dividing the octave into 12 isn't the only possible system (a lot of folk music uses a five-note octave), but 12 divides neatly by 2, 3, 4 and 6, which makes it easy to construct ratios that correspond closely to harmonious note combinations. ***LV***

NATURE'S WEIRDEST CREATURES

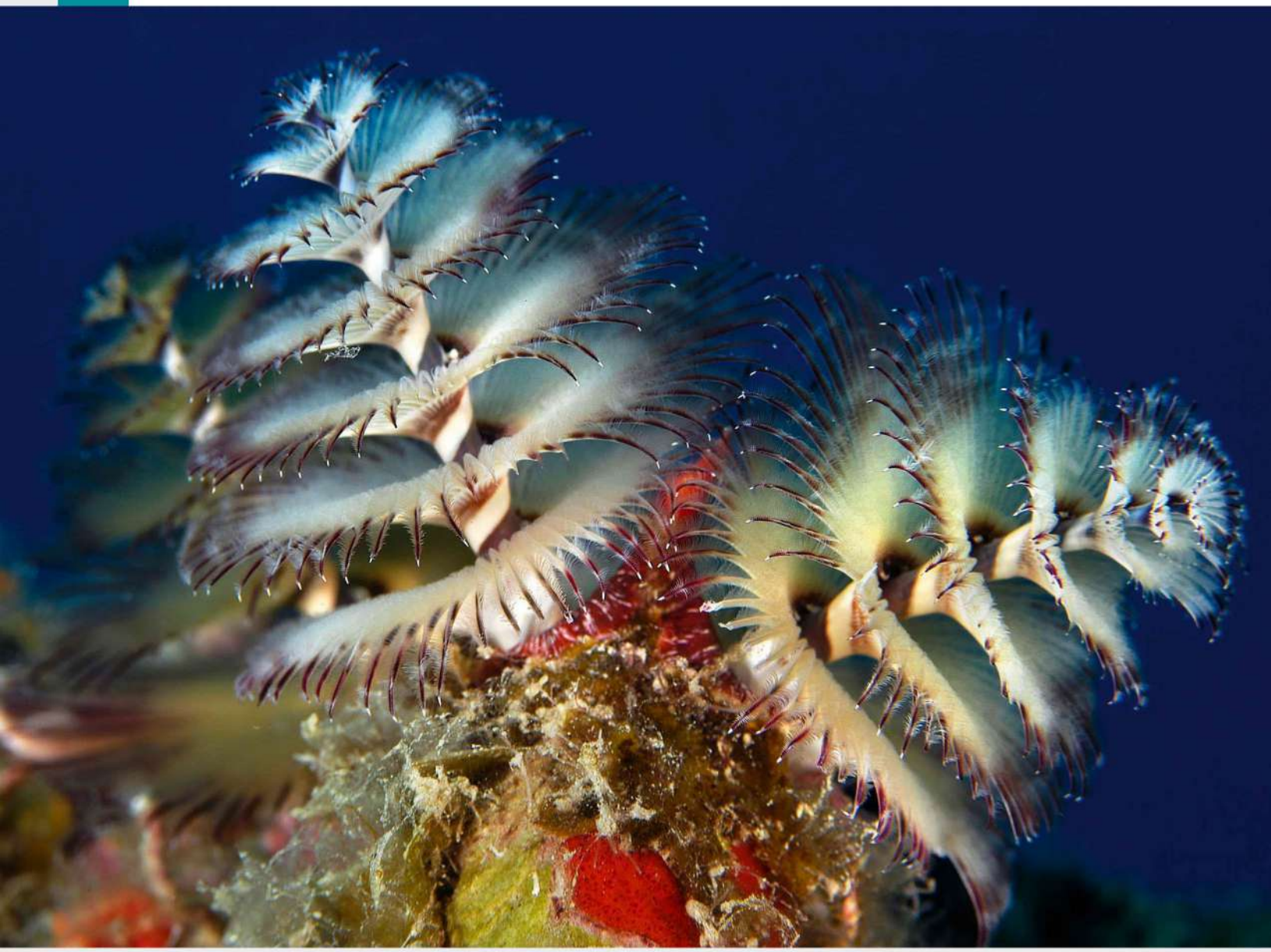
CHRISTMAS TREE WORM

A game I like to play while scuba diving or snorkelling on a tropical coral reef is to slowly glide up to a boulder of coral and peer as closely as I can at clusters of Christmas tree worms without scaring them. These tiny creatures look remarkably like tiny fir trees, although the artificial kind made of brightly coloured plastic and tinsel. They can grow in rainbow mixtures of reds, yellows, oranges and blues, and all of them are the same single species, *Spirobranchus giganteus*.

Get too close and, in the blink of an eye, the reclusive worms disappear into their tubes, which are burrowed into the coral, and slam shut little lids, operculums, behind them. Then it's a wait of a minute or longer before the worms decide it's safe to come back out.

Christmas tree worms can reach lengths of around 3.5cm and most of their bodies remain hidden in their tubes. The festive parts sticking out are pairs of feathery spiral-shaped tentacles known as radioles, which they use for breathing and feeding. As well as acting as gills absorbing oxygen from seawater, the radioles filter suspended food particles and plankton, passing them towards the worms mouths with microscopic hairs, like a conveyor belt.

Close relatives of Christmas tree worms, members of the same *Sabellidae* family, include the feather duster and peacock worms, which stick up in tubes from the seabed with a mop of radioles poking out. All of these sedentary worms begin life as minute mobile larvae.



Female and male Christmas tree worms cast their eggs and sperm directly into the seawater, where they fuse and form larvae that drift for 9–12 days before settling onto a suitable piece of coral. They seem to be quite choosy, only growing on particular species such as brain corals, although it's not known exactly how they make their choice.

Once they've picked a home, a young Christmas tree worm burrows into the coral and constructs the tube it'll spend its life in, lining it with calcium carbonate. They can live for up to 30 years.

The worms' hypersensitivity, seen in their disappearing trick, comes down to an unusual feature. Nestled among their radioles are hundreds of bright orange eye spots. No other animals can see with their gills, but for these worms it makes sense to be able to scan the water while their body is burrowed within its coral host. The eye spots contain light sensitive opsin pigments, which send signals to the worms brains to warn them of shadows overhead that could be a predatory fish or crab.

Rather counterintuitively, worms in crowded neighbourhoods are more skittish than those living alone or in small communities. The more worms on a coral colony, the longer they spend hidden in their tubes. There isn't safety in numbers for Christmas tree worms, perhaps because they're just too eye-catching when lots grow together to form underwater Christmas forests. ***HS***

GETTY IMAGES X3

ALEX MADDOX, VIA EMAIL

SHOULD I BE DOING FACIAL YOGA?

Facial yoga has gained immense popularity in recent years, espoused by celebrities like Jennifer Aniston, Kate Moss and Gwyneth Paltrow. The basics are the same as full-body yoga: a series of stretches and exercises to tone and strengthen facial, neck and shoulder muscles. The process targets tensions and stresses, and devotees claim it contours and lifts areas that have become weakened over time.

But is there science behind the bizarre facial expressions? According to a small pilot study published in *JAMA Dermatology*, researchers found that participants (aged 40–65) who performed 30-minute daily or alternate-day facial exercises over 20 weeks saw a "significant improvement in upper and lower cheek fullness". More than that, they reported a reduction in apparent age: 1.2 years after 8 weeks, and 2.7 years after 20 weeks.

Facial yoga is also thought to have a positive effect on mental health. A review of studies in the *International Journal of Environmental Research and Public Health* found that voluntary facial muscle exercise may improve depressive symptoms, mood and reduce the level of chronic stress. There is also evidence to suggest that stretching and massage might have a positive impact on reducing the appearance of scars.

However, a review in the *National Library of Medicine* notes the need for further, large and randomised controlled trials before facial yoga can truly be touted as the next best thing in anti-ageing. ***VHG***

4 FACIAL YOGA EXERCISES TO TRY AT HOME

As with any new regime, it's advisable to consult a health practitioner to determine if yoga is right for you. If it is, here are some exercises to get you started...

Cheek puff

Purse your lips and puff out your cheeks, transferring the air between cheeks as you do so. Hold for 5 seconds, release and repeat. This can help tone your cheek muscles.

Eye rejuvenator

Gently tap the skin under your eye, gradually moving the taps towards the inner corner of your eye. Move up and above your eye towards the outer corner. This helps with lymphatic drainage, which can reduce dark circles and puffiness.

Fish face

Purse your lips, then suck in your cheeks. Hold this pose for around 30 seconds, release and repeat. This is often considered the 'classic' facial yoga pose, targeting the jawline and cheek muscles.

Frown preventor

Using your index and middle finger between your eyebrows, gently press down and open your fingers so they travel along your eyebrows. Hold for 5 seconds, release and repeat.

CARRIE MUELLER, TUNBRIDGE WELLS

WHAT IS DECISION PARALYSIS AND HOW DO I DEAL WITH IT?

If you've ever gone online to order something during a work break – let's say a new electric toothbrush – expecting it to be fairly straightforward, but instead you found yourself overwhelmed by the huge number of choices and options available, you've experienced decision paralysis.

You're stunned that there are so many factors to consider; not only the basics, such as price and delivery time, but there are many other factors like battery duration, warning lights for excessive pressure and even fancy apps. The clock is ticking on your break and it's impossible to make a decision.

This is just one example of decision paralysis – when the sheer number of options and the difficulty of weighing them all up – leads you to freeze. It used to be thought that increased choice could only be a good thing for consumers and they would welcome it, but actually it can backfire and prompt people to walk away.

In other life situations, it might be the weight of the decision that bears down on you. Perhaps you only have two or three choices, but the risk of making the wrong decision can be paralysing, such as choosing between university places, job offers or even potential romantic partners.

Whatever the context, decision paralysis is more likely to strike if you're what psychologists call a 'maximiser' – that is, you're highly motivated to find the best choice possible. In contrast, you're less likely to be afflicted if you're a 'satisficer', in which case you're happy making a 'good enough' choice, regardless of whether it's the best of all.

Also relevant is your sense of anticipated regret about making a wrong decision. The more you feel this, the more likely you'll be paralysed. In turn, this is related to what you consider to be the 'opportunity costs' of making a decision. Simply put, this is all that you'll miss out on once you choose to go down a particular path.

There are various ways to overcome decision paralysis. One is to recognise that there is rarely any such thing as the perfect decision, especially without a crystal ball. Another is to acknowledge that not making a decision is actually a decision – so don't kid yourself that endlessly procrastinating is the easy solution.

If you're willing to put in the effort, a practical approach is to reduce the mental complexity involved in a decision by doing a little research and making some brief notes about the main factors that are important to you in order of priority.

In the case of the toothbrush, this might be price first and then battery duration; in the case of choosing a university it might be prestige first, then friends who are also planning to study there, and lastly proximity to home. Score the available options against those factors, giving greater weight to those that are higher priority. You'll end up with a numerical score showing you the most favourable decision. And if it's a tie, you could always roll a dice. ***CJ***

ESTHER LAMB, WORTHING

IS IT TRUE THAT YOU'RE ALWAYS WITHIN 6 FEET OF A RAT?

This claim has been around for at least 100 years, but no one quite knows where it originated. Experts agree that unless you live in a sewer, it's categorically false.

Part of the problem is that we know little about rats' secretive lives or how many there are. A report by Natural England in 2018 put the British rat population at 7 million, but according to the British Pest Control Association it could be 120 million.

Whatever their number, British rats are not evenly dispersed. They're completely absent from parts of the Scottish Highlands and you're unlikely to be near one in the middle of the English countryside unless you're near a barn. Rats are commensal, meaning they live near humans and their next easy meal.

Even in urban environments, like London, it's tricky to know how many rats are scurrying about. In 2012, Dave Cowan, who led the wildlife programme at the Food and Environment Research Agency, told the BBC that about 3.5 million rats live in UK cities. Meanwhile, some exterminators (who admittedly have a vested interest) claim the capital has almost 20 million of the rodents.

Let's assume the worst. If London, with an area of 1,572km^2 (607 miles^2), had 20 million evenly dispersed rats, each one would have 78.6m^2 to itself, meaning you'd likely be within 5m (16.4ft) of a rat. With the more conservative estimate of 3 million, your nearest rat would be around 13m (42ft) away.

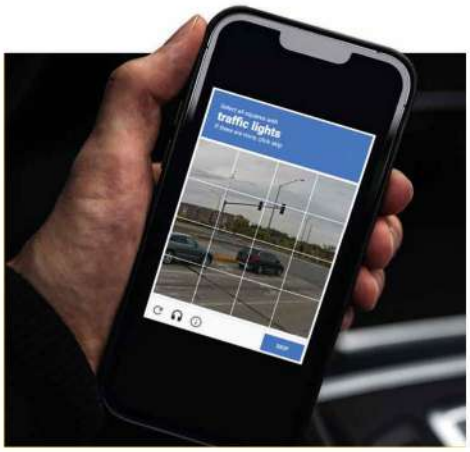
Take heart though: the myth that New York City has a rat for each of the 8.5 million people living there was roundly debunked in 2023, when a study found that the Big Apple contained no more than 3 million rats, or approximately one for every three residents.

Again, rats are not dispersed evenly. They congregate where food is available (near bins, restaurants or markets) and foot traffic is low (sewers, abandoned buildings or construction sites). They rarely climb above the first floor or stray more than 200m (650ft) from where they're born, so you can easily find spots free from the whiskered wanderers. ***CP***

GETTY X2 ILLUSTRATIONS: SEBASTIEN THIBAULT, PETE LAWRENCE

STEVE HUNT, VIA EMAIL

IF AI IS MEANT TO BE SO INTELLIGENT, WHY CAN'T IT IDENTIFY A SET OF TRAFFIC LIGHTS?

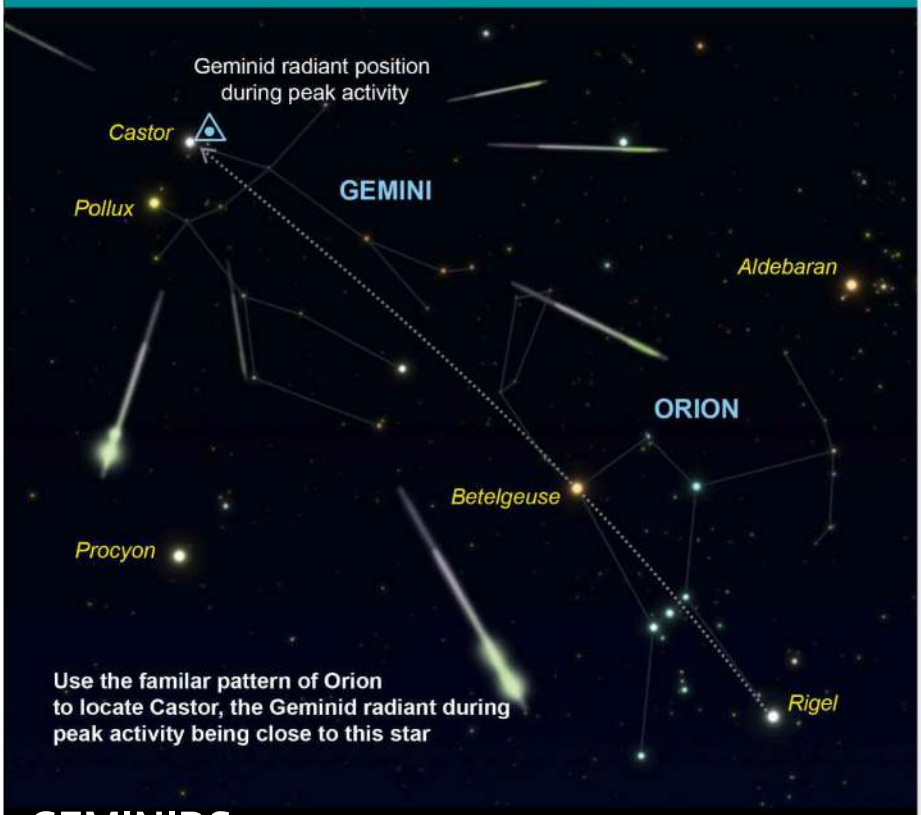


It can. Artificial intelligence (AI) is so powerful today that most CAPTCHA images can be easily solved. A CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) is often an image or distorted text that you need to identify or interpret to prove you're human. Originally, the idea of image-based CAPTCHAs, named reCAPTCHA, was also to help train AIs to perform text recognition better when digitising books. Invented by Luis von Ahn (co-founder of Duolingo), poorly scanned words were shown to humans as a CAPTCHA and by identifying them, we taught the AIs.

We no longer need to train AIs this way – they're more than able to cope. Research reported in July 2023 showed that most can solve CAPTCHA images with 96 per cent accuracy, compared to humans who range from 50–86 per cent. The AIs are even adept at mimicking humans to fool the bot detectors, by copying our poor accuracy, for example, or even our mouse movements as we figure out which boxes to click.

Yes, today's reCAPTCHAs are remarkably advanced security systems behind the scenes. Even the 'I'm not a robot' box has multiple levels of encryption as it measures a surprising amount of data about you: your time zone, IP address, screen size, browser and plugins, key presses, mouse clicks, browsing history and things we may not know about. But will AIs soon be able to fools these too? Yes. ***PB***

ASTRONOMY FOR BEGINNERS



GEMINIDS

WHEN: MID – LATE DECEMBER

Some years are good for seeing meteor showers, some not so good. Visibility, and so the spectacle of the event, is determined by sky quality – a function of the degree of light pollution, weather and the Moon's presence.

You can do something about light pollution and possibly the weather by planning ahead and moving location if yours doesn't look promising. The Moon is less easy to deal with: when big and bright in the sky, it'll drown out all but the clearest meteor trails.

The Geminid meteor shower is arguably the best of the year. Occurring between 4–17 December, its peak – on the nights of 12/13, 13/14 and 14/15 – is high and also broad in terms of how long it lasts. And in 2023, the Moon is new on 12 December, meaning it won't interfere at all. Given clear skies, there's a chance of up to 12 hours of darkness each night.

Geminid meteors have an odd source: the asteroid 3200 Phaethon. Described as a 'rock-comet', this object typically has sand-grain sized particles strewn around its orbit, which vaporise when they encounter Earth's atmosphere to produce a meteor trail. A perspective effect makes the meteors emanate from a location close to the star Castor in the constellation of Gemini at peak activity.

At that time, the Gemind's zenithal hourly rate (the number of meteors you'd expect to see under perfect conditions) would be around 120. In practice, the number will be lower, but still high enough to be impressive.

All you need to observe the Geminid meteor shower is your eyes (give them 20 minutes in darkness before starting a watch). Wrap up warm, lay back on a sun-lounger or equivalent, and look up at an angle of around 60 degrees, or two-thirds up the sky, in any direction, although to the south there will be some great stars and planets on view. *PL*

by **PETE LAWRENCE**
(@Avertedvision)
Pete is an astronomy expert and presenter on The Sky at Night.

WATCH *THE SKY AT NIGHT* ON BBC FOUR AND BBC IPLAYER
BBC FOUR

OUR LUNAR LEGACY

The Moon has always offered the promise of adventure and discovery, which has driven space exploration for generations...

1958

The first attempt is made to reach the Moon by NASA's space probe Pioneer 0. It explodes 77 seconds after lift-off.

1959

The Soviet Union's Luna 2 impacts the Moon, becoming the first human-made object to reach another celestial body.

1959

Luna 3 successfully returns images that provide the first glimpse of the far side of the Moon.

Going back to the Moon

ARTEMIS AND A NEW DAWN OF LUNAR EXPLORATION

INFOGRAPHIC BY JAMES ROUND

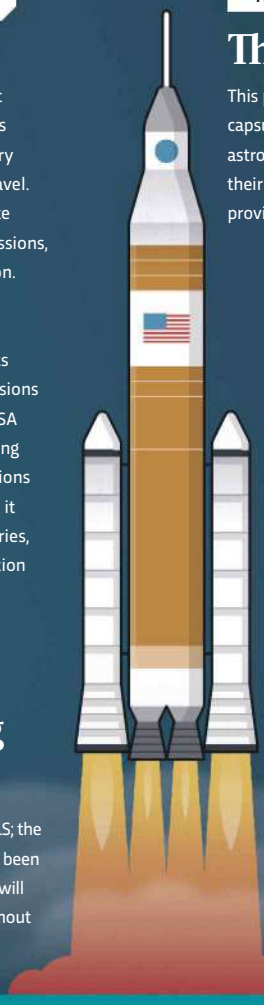
When Neil Armstrong took his iconic first steps on the lunar surface, it was a defining moment of the 20th century and beckoned a new age of space travel. But those ambitions were never quite realised and after just six crewed missions, humans never went back to the Moon.

That's all about to change. Scientists continue to uncover amazing insights about the Moon, with upcoming missions aiming to reveal even more. And NASA wants boots on the ground, embarking on an ambitious series of lunar missions through the Artemis program, which it hopes will provide scientific discoveries, economic opportunities and inspiration for a new generation.

THE ARTEMIS ROCKET

Space Landing System (SLS)

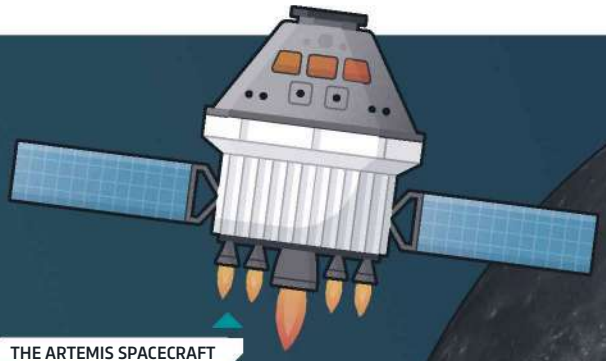
Every mission will start with NASA's SLS; the world's most powerful rocket. It's only been used once so far, during Artemis I, but will transport both cargo and crew throughout the duration of the Artemis program.



THE ARTEMIS SPACECRAFT

The Orion

This partially reusable, next-generation capsule can transport a crew of four astronauts into space, sustain them during their journey to and from the Moon, and provide safe re-entry back to Earth.



MOON MAP KEY

The map displays notable lunar landmarks, as well as every spacecraft to land on the Moon's surface.*

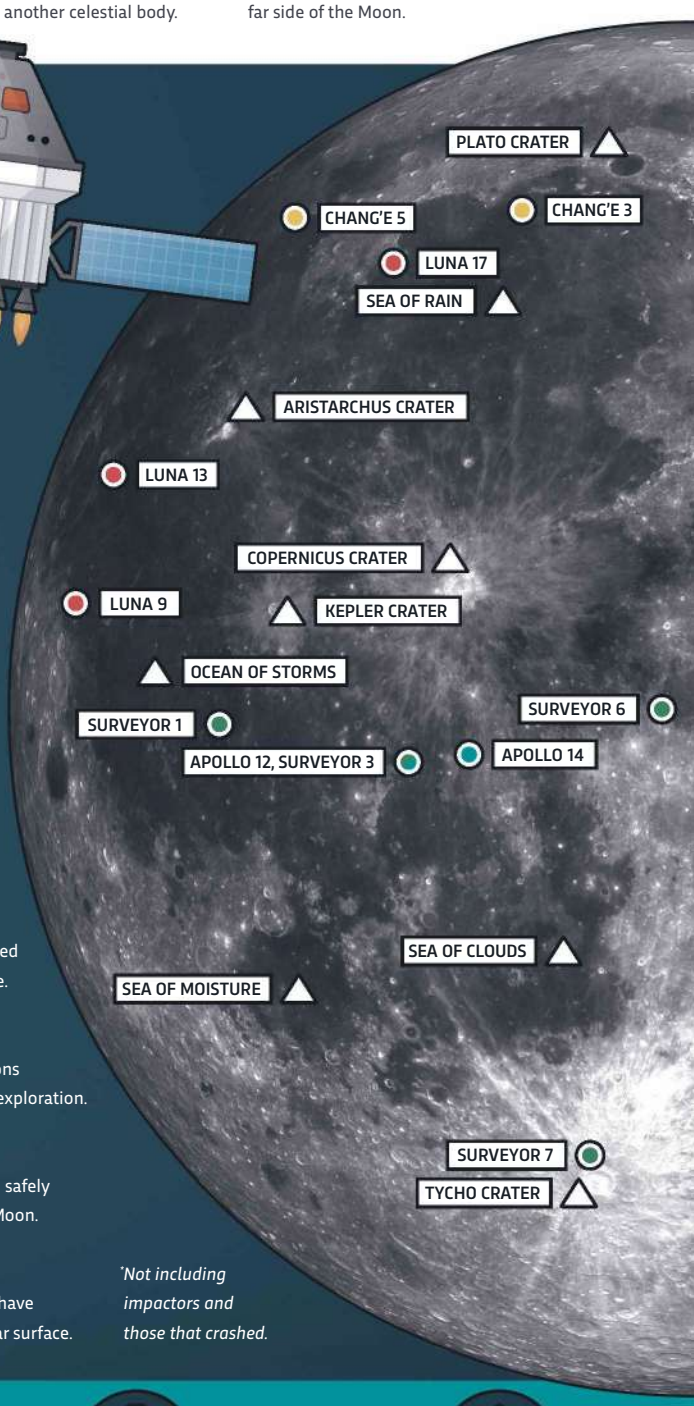
MOON LANDMARK

APOLLO (1961–1972)
NASA's Apollo missions delivered 24 humans to the lunar surface.

LUNA (1959–1976)
The Soviet Union's Luna missions achieved many firsts in space exploration.

SURVEYOR (1966–1968)
NASA's other lunar programme safely landed five spacecraft on the Moon.

OTHER LANDING SITES
More recently other countries have succeeded in reaching the lunar surface.



*Not including impactors and those that crashed.

THE ARTEMIS MISSIONS

This NASA-led lunar exploration program includes six other space agencies as well as a number of private space-flight companies and will, over the next decade and beyond, seek to establish a permanent human presence on the Moon.

ARTEMIS I

NOVEMBER 2022

Marking NASA's first return to lunar exploration since the Apollo program, Artemis I demonstrated that the Orion spacecraft and Space Launch System (SLS) rocket were ready for crewed flight.

ARTEMIS II

NOVEMBER 2024

In this 10-day mission, the Orion spacecraft and a crew of four NASA astronauts will perform a flyby of the Moon and return to Earth; the first crewed mission beyond low Earth orbit since Apollo 17 in 1972.

ARTEMIS III

NOVEMBER 2025

Astronauts will land in the Moon's southern polar region and take the first steps on the lunar surface in over five decades. The crew will include the first women and the first person of colour to land on the Moon.

1966

Luna 9 becomes the first spacecraft to achieve a soft-landing on the Moon and shares the first pictures from the surface.

1968

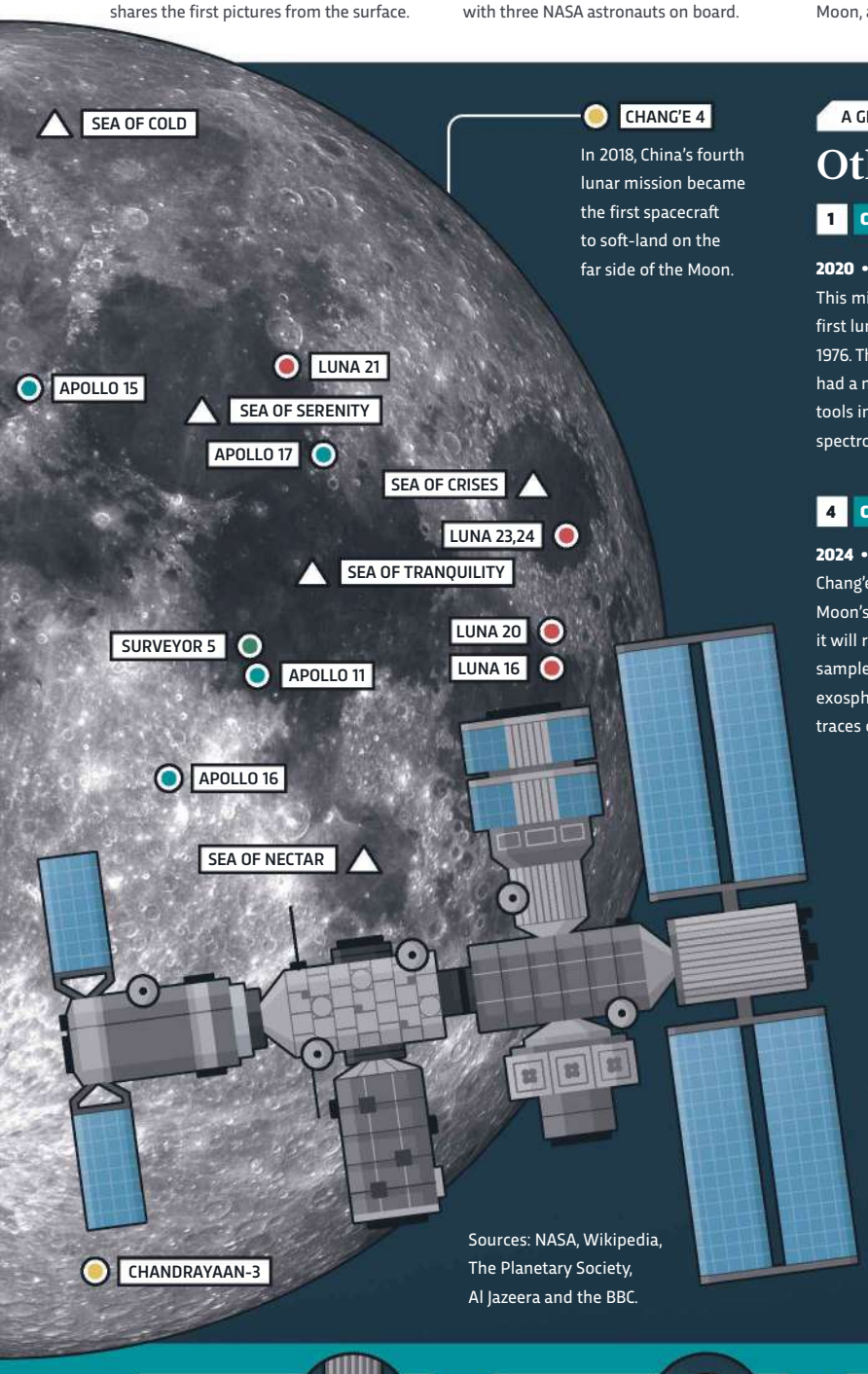
Apollo 8 becomes the first crewed mission, as it orbits the Moon 10 times with three NASA astronauts on board.

1969

Neil Armstrong makes history as he becomes the first person to walk on the Moon, as part of the Apollo 11 mission.

2009

NASA's Lunar Reconnaissance Orbiter launches, with a mission to map the lunar surface. It remains operational.



In 2018, China's fourth lunar mission became the first spacecraft to soft-land on the far side of the Moon.

Sources: NASA, Wikipedia, The Planetary Society, Al Jazeera and the BBC.

A GLOBAL ENDEAVOUR

Other Moon missions

1 Chang'e 5

2020 • China

This mission returned the first lunar sample since 1976. The spacecraft also had a number of scientific tools including cameras, a spectrometer and a radar.

2 Danuri

2022 • South Korea

Also known as the Korea Pathfinder Lunar Orbiter, this orbiter is designed to survey lunar resources and map the lunar surface to inform future landing sites.

3 Chandrayaan-3

2023 • India

This mission helped India become the fouth nation to reach the lunar surface. The mission was intended to study the Moon's composition.

4 Chang'e 6

2024 • China & Pakistan

Chang'e 6 will land on the Moon's far side, where it will return a lunar sample, study the Moon's exosphere and detect ice traces on the lunar surface.

5 Beresheet2

2025 • Israel

This private space mission will include an orbiter and two lunar landers, with the aim of giving students educational opportunities in space science.

6 Chandrayaan-4

2026 • India & Japan

This mission will explore the Moon's south pole with a lunar lander and rover, collecting sub-surface samples and looking for evidence of water.

THE ARTEMIS LUNAR LANDER

Starship HLS

The Human Landing System (HLS) is SpaceX's lunar lander and will be used to transfer Artemis astronauts from orbit, either in the Orion spacecraft or from the Lunar Gateway, down to the lunar surface.

THE ARTEMIS SPACE STATION

Lunar gateway

Before reaching the Moon, astronauts will dock at the Gateway, a space station in lunar orbit, featuring a laboratory, accommodation and a holding area for rovers and robots.

ARTEMIS IV

SEPTEMBER 2028

As well as a second lunar landing, Artemis IV will see the arrival of the Lunar Gateway's habitat module, enabling further development of the space station with other sections delivered by SpaceX.

ARTEMIS V

SEPTEMBER 2029

The fifth Artemis mission will see a third lunar landing, but with this one using Blue Origin's Blue Moon to reach the surface. Previous missions will have used SpaceX's Starship HLS as a lunar lander.

FUTURE MISSIONS

Six other missions are planned as part of the Artemis program, including more crewed missions, further development of the Lunar Gateway and the construction of a base on the Moon's surface.

BEYOND ARTEMIS

For now, the Artemis program is focused on the Moon, but looking further ahead NASA has bigger plans. In the long-term, Artemis is just one step on a journey that will eventually take humans to Mars.

DEAR DOCTOR

WHY DO I LOVE SPICY FOOD, WHEN IT DOESN'T ALWAYS LOVE ME? WHAT CAN I DO?

It's unlikely that spicy food will ever love you, if it doesn't already. But keep up the good work and continue to eat it regularly because as well as creating the taste sensations you crave, chilli is also good for you. Some studies suggest that people who consume it regularly are healthier and live longer than non-chilli eaters.

Beyond that, being a chilli-lover can also reveal aspects of your personality to the wider world. Research at Pennsylvania State University, US, suggests that 'sensation-seekers' with a sensitivity to reward are more likely than other types of people to turn to foods containing chilli.

Chilli gets its heat from a chemical irritant called capsaicin. This has anti-inflammatory effects and may help to regulate a person's blood pressure and lower the risk of obesity, although more research is needed in this area. Also, laboratory tests suggest that capsaicin may boost the diversity of gut bacteria.

Capsaicin causes a burning sensation by locking onto a particular type of receptor in the body, including in the mouth and gut. The TRPV1 receptor is activated by heat and is involved in sending spicy signals to the brain. After an initial burn, TRPV1 activation has an analgesic effect, which explains why capsaicin is present in some over-the-counter creams or gels to treat chronic pain.

When it comes to what we eat, though, researchers have long puzzled over the human fondness for spicy food when most other animals won't go near capsaicin. Chilli pepper plants produce the chemical as a deterrent to stop herbivores munching them. Birds can only tolerate chilli because of mutations in their TRPV1 receptors.

But back to your question: can you improve your body's tolerance to capsaicin?

There is some truth that a glass of milk may help, at least with mouth burn. In 2022, a team from Pennsylvania State looked into how it can reduce the burning sensation caused by capsaicin and found that milk proteins bind to capsaicin, which may make the substance less available for activating TRPV1 receptors. In tests on humans, they found capsaicin's 'maximum burn intensity' to decrease in the presence of higher levels of milk proteins called caseins.

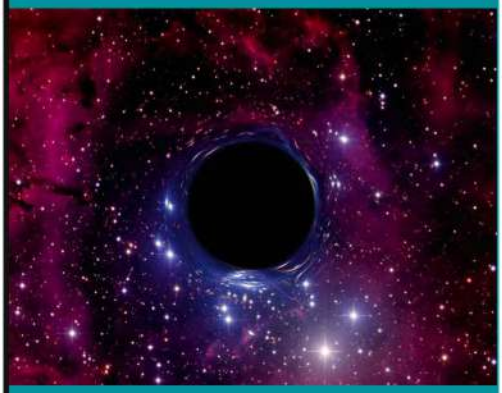
Another study from the same university looked at the efficacy of common beverages in reducing capsaicin's mouth burn. Tests showed that while all beverages reduced the burn to a certain extent, milk or a non-carbonated, sugar-laden drink were the most effective. Carbonated beverages were not much use, possibly because of their carbonic acid.

Some speculate that fat helps, although studies have shown full-fat milk to be no more effective than skimmed. In tests, increasing the amounts of fat added to both cheese sauce and a starch paste containing capsaicin reduced the burn relative to fat-free products. This may be because capsaicin is far happier in fat than in water, limiting the number of molecules available to bind to the TRPV1 receptors.

In the same way, eating your spicy food with a starchy side, such as bread or rice, may prevent so many of the capsaicin molecules from hitting the receptors. ***ED***

ALED WEAVER, WIGAN

HOW MANY BLACK HOLES ARE THERE IN THE MILKY WAY?



'Stellar' black holes form when massive stars collapse under their own gravity at the end of their lives. We know that a star must have an initial mass of between 15–20 solar masses in order to collapse and form a stellar black hole. We also have a pretty good idea of the distribution of stellar masses in the Milky Way. These two facts tell us that about one in 1,000 stars has the potential to become a black hole. An estimate of the number of stars in the Milky Way, 100 billion stars, then implies there could be up to 100 million stellar black holes in the Milky Way. ***AG***

DIANE BERRY, VIA EMAIL

WHAT IS A WANDERING STAR?

Wandering stars, also called 'intergalactic stars', 'intracluster stars' or 'rogue stars', are stars that are not gravitationally tied to a particular galaxy – they exist between galaxies. These stars, first discovered in 1997, probably formed inside galaxies, but were later expelled, perhaps during galaxy mergers or by a close encounter with a supermassive black hole. Astronomers estimate that rogue stars comprise between 15–50 per cent of all stars in galaxy clusters. The Virgo galaxy cluster, for example, contains perhaps 1 trillion rogue stars! Closer to home, at least 675 rogue stars have been found between the Milky Way and the Andromeda Galaxy. ***AG***

HEATHER WARREN, VIA EMAIL

IF CONDITIONS ON EARTH CHANGED, IS IT POSSIBLE DINOSAURS COULD EVOLVE AGAIN? WOULD LIFE... FIND A WAY?

Dinosaurs are still with us, in the form of birds. But could the more canonical dinosaurs, like *Tyrannosaurus* and *Triceratops*, evolve again, if the climate and temperature switched back to what the conditions were like during the Cretaceous? Probably not.

While it's a fun thought experiment, we really can't predict what will evolve in the future. So much about evolution is down to contingency, luck and chance. Natural selection can't plan ahead; it happens in the moment, to adapt organisms to immediate challenges. As the late and great American paleontologist Stephen Jay Gould mused: what would happen if we rewound the tape of life to some distant time and hit play? When it reached the present day, would the world be the same as it is now? He argued it would be different, perhaps much so.

Nothing is inevitable in evolution and little random quirks would set life off on unpredictable paths, different each time the tape was rewound and replayed.

The more we study the fossil record, the more we realise that extinction is forever. Once a species or a group dies out, it just doesn't come back. Take trilobites, for example. Climates today are broadly similar to those during times that they flourished in the oceans, yet trilobites haven't returned.

So what about something *similar* to dinosaurs, could they evolve? It's possible. A powerful force in evolution is convergence: if different species face the same climate and environmental factors, they often evolve similar features to adapt to their surroundings. For instance, both dinosaurs (birds) and mammals (bats) independently evolved wings to fly.

If the Earth lurched into a Cretaceous-like climate, *Tyrannosaurus* and *Triceratops* would surely not re-evolve, but other large, lumbering, sublime reptiles might. ***SB***

QUESTION OF THE MONTH

PHOEBE FARRELL VIA EMAIL

CAN YOU SMELL ANTS?

Ants may be little, but they can pack a pungent punch. Many species of ants release strong-smelling chemicals when they're angry, threatened or being squished. Trap-jaw ants release a chocolatey smell when annoyed, while citronella ants earned their name from the lemony odour they give off.

The scent of the odorous house ant, meanwhile, has been likened to blue cheese or rancid coconuts. This is because the chemicals that it releases, methyl ketones, are also produced by the *Penicillium* bacteria that ripen blue cheese and grow on rotting coconuts.

Formic acid is another stinky substance emitted by many ant species. Wood ants, for example, produce large quantities of the vinegary substance in their venom gland to spray at prey and attackers. And when ants die of natural causes, they release oleic acid, the main fatty acid found in olive oil. This gives dead ants a 'freshly dressed salad' sort of smell, which acts as a chemical cue for the rest of the colony to clean up the bodies before they start to decompose.

Scents, however, are just the tip of the iceberg since ants have an entire language based on smell.

Is it possible for us to speak that language? An ad-hoc poll of around 700 people on X, formerly known as Twitter, revealed that only 20 per cent of respondents claimed an ability to smell ants. The rest were a bit bamboozled.

This imbalance may simply reflect a lack of curiosity – after all, many people have never tried to smell an ant – but genetics is also likely to play a role. Just as some people are unable to sniff out 'asparagus urine' due to a mutation in a key smell-related gene, so too a blip in the genetic code may prevent some people from detecting key ant scents. ***HP***

WINNER

The winner of next issue's *Question of the Month* wins a **trio of hardback popular science books**: *Most Delicious Poison*; *Putting Ourselves Back in the Equation*; and *Starborn* – worth over £65.

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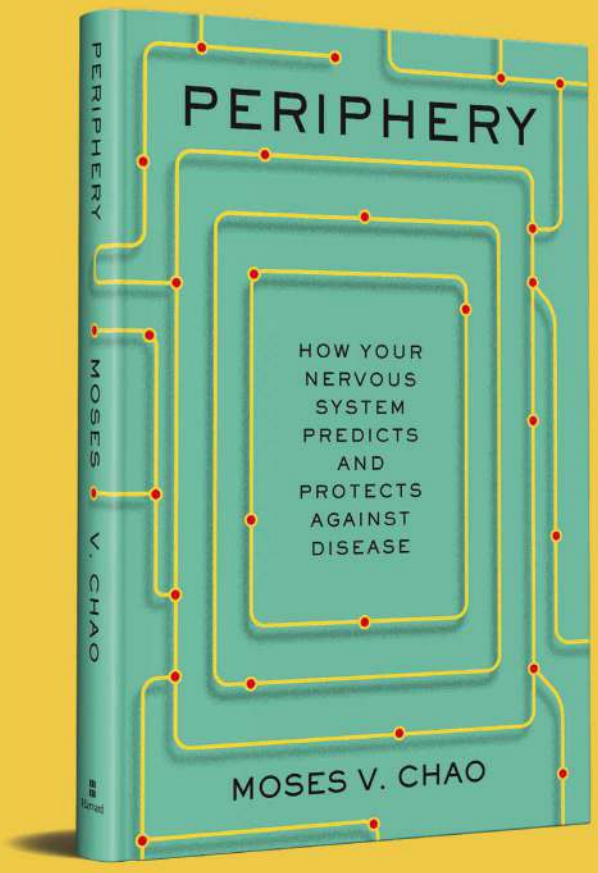

A leading neuroscientist argues that the peripheral nervous system, long understood to play a key role in regulating basic bodily functions, also signals the onset of neurological disease.

Harvard University Press
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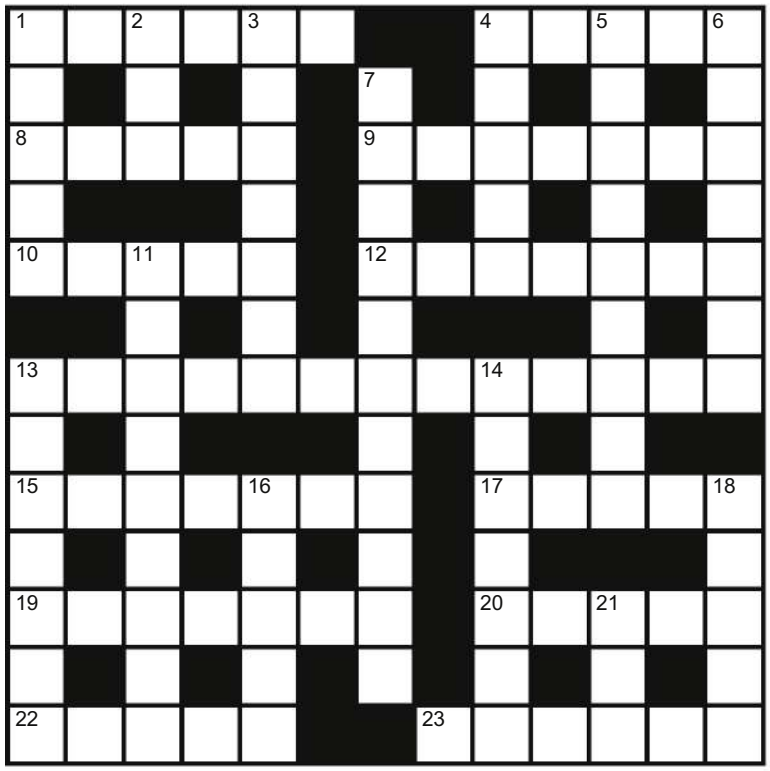

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8 Quiet pixie getting some storage (5)
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17 Reproduction of steel in bad conditions (5)
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3 Leaving summit when there's less demand (3-4)
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5 Deity atrophied, sadly (9)
6 Radical old meter following renovation (7)
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18 Sentimental start to the message (5)
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ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

NEXT ISSUE

SCIENCE IN 2024

The biggest stories expected to make headlines in the year ahead

GETTY IMAGES

PLUS

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How to make your metabolism run faster... Or slower

2023 IN PICTURES

Look back over the last 12 months with the year's best science photography

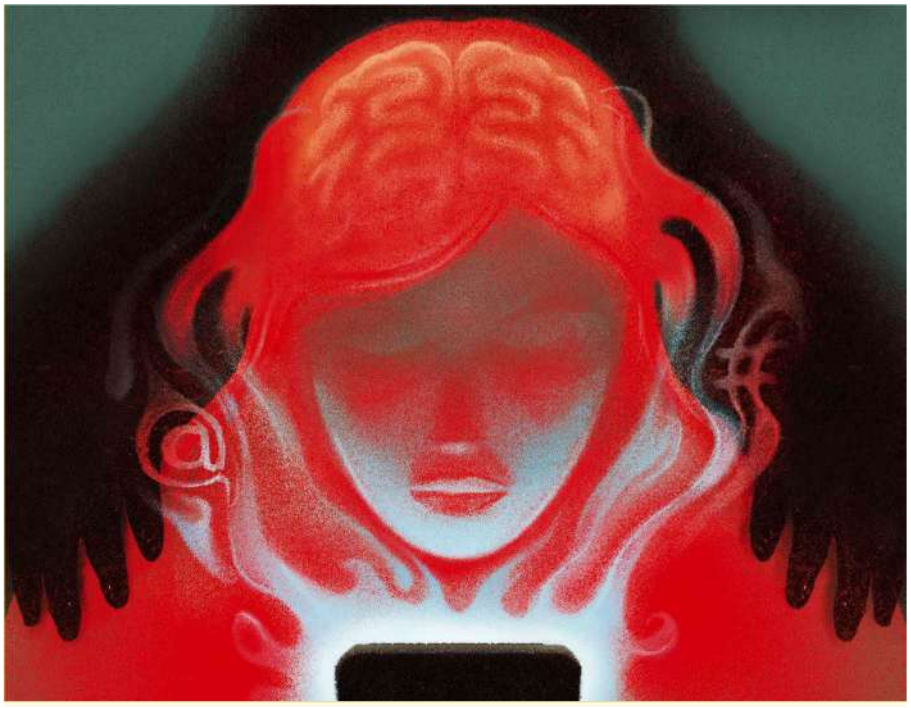
ON SALE 29 DECEMBER

SF

BETTER LIVING THROUGH SCIENCE

SCROLL REVERSAL

Losing days by endlessly scrolling on your smartphone? You're not alone. Perhaps neuroscience can help us beat the urge...



According to Ofcom, the UK's communications regulator, the average Brit checks their phone every 12 minutes. For many of us, it's the first thing we do in the morning and the last thing we do at night. It's a nagging, persistent compulsion, driven by molecules in our brains.

One molecule in particular is usually blamed for this kind of behaviour: dopamine. The neurotransmitter has been nicknamed the 'feel-good' molecule due to its role in the brain's reward system. But it's not just about pleasure – dopamine receptors in the brain also get a hit with the anticipation of something pleasurable. And that's what keeps us checking our phones.

Mobile games and social media apps are designed to maintain that compulsion.

Anna Lembke is a professor of psychiatry and behavioural sciences at Stanford University. She believes that the smartphone is akin to a hypodermic needle, delivering an endless supply of 'digital dopamine' to billions of users.

"Digital media activates the same part of our brains as drugs and alcohol, releasing dopamine," says Lembke. "With repeated use, our brains adapt by downregulating dopamine transmission." Which they can do by shrinking their dopamine receptors.

"THE SMARTPHONE IS AKIN TO A HYPODERMIC NEEDLE, DELIVERING AN ENDLESS SUPPLY OF DIGITAL DOPAMINE"

"With enough ongoing exposure, our brains enter a dopamine deficit state, characterised by depression, anxiety, insomnia, irritability and craving. Once that happens, we're reaching for digital media not as a tool to accomplish a specific task... but to get out of the dopamine deficit state and stop feeling bad."

Behavioural addictions like compulsive social media use are the subject of much debate. There are some who don't believe they should be discussed on a par with substance abuse because, while using digital media does increase the release of dopamine, it does so by far lower amounts than cocaine or methamphetamines.

Nevertheless, 2023 research from Brown University found that among adolescent girls on TikTok, around half felt addicted to it.

Addicted or not, we Brits spend on average four hours a day on our phones. Most of us would probably like to claw some of that time back. So, can we use our knowledge of the brain's reward system to loosen the smartphone's grip on us? Possibly...

One idea you may have heard about (on Instagram or TikTok, ironically) is dopamine fasting.

It's a form of meditation or cognitive behavioural therapy, a practice by which you try to limit compulsive urges and change behaviours. The idea is that you consciously cut yourself off from the things you're overstimulated by – social media, for example – for a short time.

Proponents claim that a brief period of abstinence allows them to better engage with the things they actually like, while developing a healthier relationship with technology. Critics, however, warn that there's little evidence to support the claims.

Even so, researchers whose work looks at excessive social media use often agree that some kind of digital detox may be a good thing.

"I'm a strong advocate of social media fasting," says Daria Kuss, a psychiatrist and professor of psychology at Nottingham Trent University. "A weekend of it may help reset behaviours in such a way that the habitual use of social media may be broken."

"My research shows that spending time with friends and family outside of social media, in the offline world, creates positive emotions, strengthens bonding experiences and feelings of connection," Kuss says. "Meeting a friend for coffee may therefore be a more positive experience than chatting with them on Messenger." **SF**

TAKEAWAY ADVICE

Start small. If you can't face deleting the apps you spend too much time on, try hiding your phone in a drawer at certain times of the day.

by IAN TAYLOR
Ian is a freelance science writer and the former deputy editor of BBC Science Focus.

ILLUSTRATION: EOIN RYAN

This was Sylvia's promise to you...

A generation ago, a woman named Sylvia made a promise. As a doctor's secretary, she'd watched stroke destroy the lives of so many people. She was determined to make sure we could all live in a world where we're far less likely to lose our lives to stroke.

She kept her promise, and a gift to the Stroke Association was included in her Will. Sylvia's gift helped fund the work that made sure many more of us survive stroke now than did in her lifetime.

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